# NUCLEAR WEAPONS MATERIALS GONE MISSING:

## What Does History Teach?

Henry D. Sokolski
Editor

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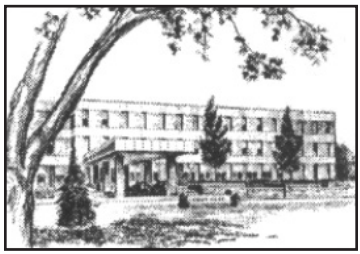

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**Henry D. Sokolski**
**Editor**

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This volume is the 18th in a series of edited volumes of contracted research the Nonproliferation Policy Education Center (NPEC) has published in cooperation with the Strategic Studies Institute of the U.S. Army War College. The volume features research done over the last 2 years. Funding for this project came from the U.S. Department of Defense, the Carnegie Corporation of New York, and other charitable foundations. Much of the work to prepare the book for publication was undertaken by NPEC's research associate, Kate Harrison, and the staff of the Strategic

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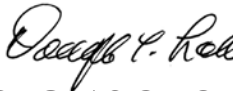
## FOREWORD

In 2009, the President of the United States spotlighted nuclear terrorism as one of the top threats to international security and launched an international effort to identify, secure, and dispose of global stocks of weapons-usable nuclear materials—namely highly enriched uranium and weapons-grade plutonium. Since that time, three nuclear security summits have been held, along with scores of studies and workshops (official and unofficial), drawing sustained high-level attention to the threat posed by these materials. However, little attention has been given to incidences where sensitive nuclear materials actually went missing.

This volume seeks to correct this deficiency, examining incidences of material unaccounted for (MUF) arising from U.S. and South African nuclear weapons programs, plutonium gone missing from Japanese and British civilian production facilities, and a theft of highly enriched uranium from a U.S. military contractor in the 1960s that was used to help fuel Israel's nuclear weapons program. This volume also questions the likelihood that the International Atomic Energy Agency would be able to detect diversions of fissile materials, whether large or small, and the likelihood that a state could or would do anything were diversion detected.

What emerges from this book is a downbeat assessment of how likely we are to be able to account for past MUF quantities or to be able to prevent future ones.



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# CHAPTER 1

# INTRODUCTION

## MATERIALS UNACCOUNTED FOR: NUCLEAR WEAPONS MATERIALS GONE MISSING

**Henry D. Sokolski**

Ever since President Barack Obama made securing nuclear weapons assets a top priority for his global arms control agenda, guarding and disposing of these holdings have become an international priority. Every 2 years, high-profile nuclear summits on how to prevent nuclear theft and sabotage have been held—the first in Washington, DC; the second in Seoul, South Korea; and the third in The Hague, the Netherlands. With each summit, more and more states have agreed to dispose of what weapons-grade nuclear fuels they have. In between these meetings, scores of studies have been commissioned and nearly as many workshops (official and unofficial) have been held. Yet, in all of this, almost no attention has been focused on what to do about the nuclear weapons-usable plutonium and highly enriched uranium that we have lost track of. This is odd.

Although the exact quantities of materials unaccounted for (MUF) are unknown, there is no doubt they are significant. U.S. nuclear weapons MUF alone is pegged at nearly six tons—i.e., enough to fashion at least 800 low-tech, multi-kiloton bombs. Russian MUF figures are assumed easily to be as large. As for Chinese, Indian, Pakistani, Israeli, and North Korean MUF figures, though, we have only a general idea of

what they might be. The civilian production of nuclear weapons-usable plutonium in the United States, United Kingdom (UK), Japan, France, and India also is a worry. We know that specific accounting losses in the case of civilian plutonium reprocessing and fuel making in the UK and Japan have been significant—measured in scores of bombs worth. What they might be elsewhere, again, is unknown.

As for the possibility of military diversions, we now know that some of what was categorized as MUF has been spirited away to make bombs. In specific, at least 100 kilograms (kg) (and possibly much more) of U.S. weapons-grade uranium was stolen from a defense contractor in the 1960s to help fuel Israel's nuclear weapons program. Fortunately, the two largest fissile material producers, the United States and Russia, stopped making nuclear weapons-usable plutonium and uranium. Also, a small portion of the U.S. and Russian surpluses of these materials have been disposed of.

This helps at least cap the growth in MUF uncertainties. Also, so far, besides the Israeli case, there are no known cases of large nuclear thefts. Presumably, they would have become known by now. Finally, there is some solace in knowing that U.S. nuclear material accounting practices are now improved over those used during the Cold War.

Unfortunately, none of this helps answer precisely how much MUF has been produced or the extent to which we can prevent the generation of more MUF. Without these answers, reducing or capping existing nuclear weapons arsenals and blocking future nuclear proliferation must remain iffy propositions.

How likely is it that the International Atomic Energy Agency (IAEA) could detect a large amount of

MUF in a timely fashion even at declared civilian nuclear sites? What of its ability to detect smaller, incremental diversions? What of national means of detection? What can we learn from the history of civilian MUF discoveries in Japan and the UK and of military MUF in the United States and South Africa? How well can the IAEA or any existing nuclear material accountancy system track the production of special nuclear material or account for past production? What do the answers to these questions suggest with regard to the prospects of eliminating nuclear weapons and nuclear weapons material stockpiles?

As this volume makes clear, the answers are mixed at best. In the case of U.S. MUF, the discoveries of tons of material missing came well after the United States originally lost track of the material. Most of it has yet to be accounted for. The South African case remains a debate between analysts that trust what South African officials have claimed and those that still worry about persisting accounting discrepancies. In the few known IAEA MUF cases, there still are material balances outstanding that are quite large. More important, the IAEA privately admits that its ability to track production of nuclear fuels and to find covert nuclear enrichment and reprocessing plants is limited. None of this augurs well for the future. As for accounting for past production, there are clear limits.

A much larger question, of course, concerns enforcement: What, if anything, has been done when nuclear security understandings have been violated or there have been discoveries of significant amounts of MUF? In important cases, has the United States or other major states chosen to act or avert their gaze? Again, what history we have offers answers that are hardly encouraging. Too often and more often than not, the United States and its allies have averted

their gaze from intelligence that lends credence to military diversions.

This volume focuses on all of these issues. Much of the analysis is technical. Most of it, technical or not, is downbeat. The good news is that this is the first dedicated volume on this specialized topic. What questions we cannot answer now may have answers with further analysis. The key message of this volume, however, is one of limits. We may never know where considerable amounts of nuclear weapons-usable material "went." More important, the amount of MUF will only grow unless we do more to limit continued, unnecessary civilian and military material production. Whether or not that recommended limit will be recognized and honored remains to be seen.

# PART I

## CHAPTER 2

# U.S. MILITARY NUCLEAR MATERIAL UNACCOUNTED FOR: MISSING IN ACTION OR JUST SLOPPY PRACTICES?

**Charles D. Ferguson**

The standard story is that there is not much to worry about: The United States has the gold standard when it comes to accounting for fissile material, especially in the military sector. Although the U.S. Department of Energy (DOE) has acknowledged that almost six metric tons (MT) of fissile material, including plutonium, highly enriched uranium, and uranium-233—enough for at least several hundred nuclear explosives—is unaccounted for, this discrepancy mostly occurred during the rush to produce fissile material during the first few decades of the Cold War when the emphasis was on fast production rather than accurate accounting. The explanation for the large amount of material unaccounted for (MUF) is that material was sent to scrap, mixed in with other waste, stuck in piping, and otherwise characterized as "normal operating losses." As the Comptroller General of the United States stated in a 1978 report:

> For the most part, MUF is attributed by DOE and NRC [Nuclear Regulatory Commission] to such things as inaccurate measurements and difficult to measure material held up in pipes, filters and machines used in processing special nuclear material.[1]

The other main reason given was "clerical errors."[2] One could infer from that assessment that most, if

not close to all, DOE and NRC officials appeared to believe that no material was diverted.

Nonetheless, one should worry about the accounting system and the potential for diversion. In particular, one significant case of alleged insider diversion of highly enriched uranium—that could fuel several nuclear bombs—has been reported and raises concern about conventional wisdom. While one could discount this alleged incident as an anomaly because it took place in the 1960s before the current, more rigorous accounting system was established, many government reports from inspectors general of the DOE and the General Accountability Office have sounded an alarm for more than 30 years that the accounting system is not adequate. As discussed in this volume, the United States is still not meeting its most stringent standards.

If the U.S. nuclear material accounting system is not adequate, then what does that imply about nuclear-armed states that are still manufacturing and remanufacturing warheads more frequently than the United States? According to conventional thinking, if the United States is not producing fissile material and not manufacturing or remanufacturing nearly as many warheads as during the Cold War, then its accuracy in accounting for fissile material should go up. Indeed, this has been the trend. But for a nuclear-armed state still producing fissile material for military purposes such as India and Pakistan or a nuclear-armed state such as Russia, which continually remanufactures its warheads much more frequently than the United States, there may be greater gaps between the material known to be in the inventory and material unaccounted for.

## U.S. FISSILE MATERIAL PRODUCTION FOR MILITARY PURPOSES AND INVENTORY DIFFERENCES

The United States was the first nation to make nuclear weapons and subsequently amassed one of the largest stockpiles of weapons and fissile material, only to be surpassed by the Soviet Union's production. For 2 decades from the early-1940s to the mid-1960s, the United States ramped up its fissile material production in response to both external geopolitical and internal political pressures and produced several hundred MT of fissile material.

By the early 1960s, the United States had dozens of facilities, numerous buildings at these sites, and thousands of workers involved in the production and handling of fissile material. Production facilities included plutonium production reactors at Hanford, WA; and the Savannah River Site, SC; and uranium enrichment plants at Oak Ridge, TN; Paducah, KY; and Piketon, OH. Handling and storage facilities were more spread across the country and included facilities located at Los Alamos, NM; Livermore, CA; Amarillo, TX; Rocky Flats, CO; Erwin, TN; and Apollo, PA, to name a few notable sites. As a result of these widespread and numerous activities, the challenge of controlling and accounting for military nuclear materials kept growing.

By the end of 1963, the United States had a surplus of fissile material. This prompted Congress in 1964 to pass the Private Ownership of Special Nuclear Materials Act, which allowed the Atomic Energy Commission (AEC) "to sell, lease, or grant nuclear materials to industry for research and development activities."[3] Such activity could increase the difficulties in accounting for fissile material, especially as the number of commercial firms handling the material increased.

Also, in 1964, President Lyndon Johnson in his State of the Union message declared a reduction in the production of highly enriched uranium and plutonium. Consequently, Oak Ridge stopped highly enriched uranium (HEU) production, and Hanford and Savannah River Site shut down four nuclear production reactors. By the early-1970s, the United States had only four reactors in operation: the N-reactor at Hanford and three at Savannah River. In 1989, the last of the reactors at Savannah River Site was finally shut down due to safety concerns. The uranium gaseous diffusion plants at Paducah and Portsmouth continued to operate beyond 1989, but they were no longer used for HEU production purposes after 1991; the production for weapons had ended in 1964. Instead, they were subsequently used only for production of low enriched uranium for commercial purposes. Thus, by 1991, the United States had stopped producing any fissile material for military purposes but was still using and handling HEU and plutonium in weapons and naval fuel.

During the decades of fissile material production, the amounts of materials generated were shrouded in secrecy. Because these materials were used in nuclear weapons, the Naval Nuclear Propulsion Program, the Army Nuclear Power Program, and other defense-related research and development activities, revealing the exact amounts produced to the public could have jeopardized national security. At least this was the rationale throughout the Cold War.

In 1993, several years after the Cold War ended, President Bill Clinton and his administration's DOE unveiled the "Openness Initiative" to make government more open and accountable to the public. As a result, DOE began to declassify vast amounts of information, as long as it could be assured that such declas-

sification would not harm national security. A major aspect of this initiative was to reveal publicly the total quantities of highly enriched uranium and plutonium produced. A few years after this initiative began, DOE published two unprecedented reports on the HEU and plutonium inventories.

Regarding HEU, DOE reported that as of September 30, 1996, the total inventory was 740.7-MT uranium (MTU) containing 620.3 MTU-235. Importantly, the DOE report did not state the amount of HEU in waste as part of the inventory and that material was thus not included in the overall quantity. (DOE withheld the HEU report for several years.) According to DOE, "Most of the HEU in waste has been removed from the U.S. inventory as 'normal operating losses' because it is technically too difficult or uneconomical to recover."[4] Table 2-1 shows the locations and inventories of HEU as of September 30, 1996.

Note that in Table 2-1, the vast majority of HEU is listed under "Y-12 Plant, Pantex, & DoD" and is aggregated among those sites and DOD facilities for national security purposes. That particular listing does not specify the amounts for the two different HEU assays of less than and greater than 90 percent U-235, the dividing line for **weapons-grade** material, but HEU less than 90 percent U-235 is still weapons-usable; once again, this was done by DOE for national security reasons. Also, note the relatively large amount of material listed under "Miscellaneous." Despite the lack of details for these two categories, the DOE report on HEU was truly path breaking. **This report also described the inventory difference, or material unaccounted for, of HEU from 1945 through September 1996 as 3.2 MTU-235**. Half of this inventory difference is from DOE sites, and the other half is from commercial sites.

| Location | 20 to <90% U-235 | | 90% U-235 | | Total | |
|---|---|---|---|---|---|---|
| | MTU | MTU-235 | MTU | MTU-235 | MTU | MTU-235 |
| Y-12 Plant, Pantex & DoD (Department of Defense) | | | | | 651.6 | 557.4 |
| Idaho National Lab | 23.1 | 15.3 | 4.3 | 4.0 | 27.4 | 19.3 |
| Savannah River Site | 21.6 | 14.1 | 0.5 | 0.5 | 22.2 | 14.6 |
| Portsmouth Gaseous Diffusion Plant | 13.9 | 6.6 | 7.8 | 7.5 | 21.7 | 14.1 |
| Rocky Flats Environmental Technology Site | | | 6.0 | 5.8 | 6.0 | 5.6 |
| Los Alamos National Lab | 0.4 | 0.2 | 3.2 | 3.0 | 3.5 | 3.2 |
| Oak Ridge National Lab | 1.6 | 1.3 | | | 1.6 | 1.3 |
| K-25 Site | 1.4 | 0.7 | 0.1 | 0.1 | 1.5 | 0.8 |
| Sandia National Lab | 0.2 | 0.1 | 0.5 | 0.5 | 0.7 | 0.6 |
| Hanford Site | 0.5 | 0.2 | | | 0.5 | 0.2 |
| Brookhaven National Lab | 0.3 | 0.2 | | | 0.3 | 0.2 |
| Miscellaneous | 1.8 | 1.2 | 1.9 | 1.8 | 3.7 | 3.0 |
| **Total** | | | | | 740.7 | 620.3 |

**Table 2-1. U.S. HEU Inventory at Major Locations, as of September 30, 1996.[5]**

Also under the Openness Initiative, in 1996, DOE published *Plutonium: The First 50 Years* in which it described the production, acquisition, and utilization of plutonium from the period of the mid-1940s through 1994. That report identified that:

- The combined DOE and DOD accountable 1994 plutonium inventory was 99.5-MT, which included a pooled 66.1-MT for the Pantex Plant near Amarillo, TX, and the U.S. nuclear weapons stockpile;

- The U.S. plutonium balance included 2.8-MT of inventory differences, equating to 2.5 percent of the total plutonium production;
- A total of 38.2-MT of accountable weapon-grade plutonium was declared surplus to defense needs and would never be used to build nuclear weapons; and,
- The amount of plutonium contained in waste was 3.9-MT located at nine different DOE sites.[6]

In 2012, DOE published an update to that report to factor in changes to data and facilities' decommissioning and opening from the period 1994 through 2009.

> The four most significant changes since 1994 include: (a) the completion of cleanup activities at the Rocky Flats Plant in 2005; (b) material consolidation and disposition activities, especially shipments from Hanford to the Savannah River Site; (c) the 2007 declaration of an additional 9.0-MT of weapons-grade plutonium to be surplus to defense needs in the coming decades; and (d) the opening of the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico in 1999. These interrelated factors have not only resulted in decreases to total inventory and inventory differences but also increases in both surplus materials and materials written off the accountable inventory as waste.[7]

The DOE's 2012 report shows that as of September 30, 2009:

- The plutonium inventory, maintained under nuclear material control and accountability, is 95.4-MT, a 4.1-MT (4 percent) decrease to the 1994 inventory. The 95.4-MT total includes a combined Pantex and nuclear weapons stockpile of 67.7-MT. The most important factor for the reduction in inventory was the reclassifica-

tion of process residues originally set aside for plutonium recovery as waste. Of the 4.1-MT reduction, 3.5-MT (85 percent) came from Rocky Flats residues sent to WIPP [Waste Isolation Pilot Plant] for disposition;

- **The cumulative inventory difference for accountable plutonium is 2.4-MT, a 0.4-MT (14 percent) decrease to the 2.8-MT made public in the 1996 plutonium report**. The 0.4-MT decrease in the cumulative inventory difference is attributed to materials recovered during de-inventorying and closure activities at Rocky Flats (0.3-MT) and Hanford (0.1-MT). Of the current 2.4-MT of inventory difference, 1.1-MT (46 percent) is at Hanford and 0.9-MT (38 percent) at Rocky Flats. **A large portion of the remaining 2.4-MT cumulative inventory difference appears to be explained by understated removals from inventory to waste** [emphasis added];
- Plutonium surplus to defense needs is now 43.4-MT, a 5.2-MT (14 percent) increase to the 1994 declaration; and,
- The plutonium estimated in waste is 9.7-MT, a 5.8-MT (149 percent) increase to the 1994 inventory of 3.9-MT. The 5.8-MT increase is attributed to: 4.4-MT (76 percent) in new discards from the accountable inventory; 0.8-MT (330 percent) increase in Rocky Flats solid waste generated prior to 1970; 0.4-MT (84 percent) increase in Hanford high level waste tank estimates; 0.1-MT in solid waste at a commercial low-level radioactive disposal facility not included in the 1996 report, and 0.1-MT from other sites.[8]

Obviously, the relatively large changes in total inventory, inventory differences, and continuing uncertainties in knowing what is or is not accounted for raises the possibility of diversions of fissile material in the past and perhaps in the future.

In addition to the stockpiles of HEU and plutonium produced for defense purposes, the United States produced uranium-233, a fissile material, for both its military and civilian nuclear programs. Just a few kilograms (kg) of uranium-233 could be used to make a nuclear explosive. In the early-1960s, the United States wanted to test using uranium-233 in nuclear explosives because this material is more stable than plutonium at high temperatures. The stability of plutonium under high temperatures turned out to be not that great of a concern, and the interest in using uranium-233 for weapons purposes stopped by 1966. While the United States made far less uranium-233—about 2-MT with about 1.5-MT being separated from spent fuel—than HEU or weapon-grade plutonium, **a relatively large amount of uranium-233 is unaccounted for—about 123-kg**, or 0.123-MT.[9] On a percentage basis, the portion of uranium-233 unaccounted for is somewhat greater than the inventory differences in the HEU and plutonium stockpiles.

## DEFINING MATERIAL UNACCOUNTED FOR AND UNDERSTANDING WHEN IT IS A CONCERN

What exactly is meant by "material unaccounted for"? Nuclear material that cannot be accounted for is officially known as "inventory difference" material. (This name change serves the euphemistic purpose of not reminding the public that material was "un-

accounted for.") No measurement system is perfect; there will always be measurement uncertainties. Consequently, to determine if there is a legitimate concern about diversion or theft of nuclear material at a facility, one needs to know how the difference in inventory compares to the limits of errors in measuring the inventory. If the former is greater than the latter, then there may be cause for concern. To calculate the inventory difference or MUF, one needs to know how much material was known to be present at the beginning check of the inventory, how much material was removed, how much was received, and how much was measured at the end check of the inventory. In a formula, one can write this as: MUF = (Beginning Inventory + Receipts) - (Removals + Ending Inventory).

If the two quantities in parentheses balance, the MUF equals zero. But because of measurement uncertainties, the MUF will most likely not equal zero for a given inventory calculation. Every measurement will have an uncertainty; by statistically combining the individual uncertainties, one can determine the limits of error of the material unaccounted for (LEMUF). If the LEMUF is calculated at a 95 percent confidence level, the null hypothesis is that MUF is zero at a 5 percent level of significance; if the LEMUF is calculated at a 99 percent confidence level, the null hypothesis is the MUF is zero at a 1 percent level of significance. The DOE now strives for the latter level of significance. According to Dr. Thomas Cochran:

> The statistical distribution of MUF will have a given one-sigma and two-sigma range. A MUF of zero does not mean that SNM [special nuclear material] is accounted for, but can be the sum of a positive MUF due to measurement error and a diversion of an equal amount of material. The value of the sigma is impor-

> tant not just in a relative sense to the percentage of the overall inventory, but in the absolute sense to the quantity of material needed to construct a nuclear weapon (i.e., kilograms range). This importance of the absolute value of the sigma is what drives requirements for very small sigma and is a challenge for facilities handling SNM in bulk or solution form.[10]

If MUF were just due to random variations in the measurements, one would expect for a series of inventory calculations that the MUF values would sum close to zero. If instead the MUF values show a tendency toward positive values, then one would suspect that there could be biased measurements, recording mistakes, unknown or unrecorded inventory, or losses or thefts of material. If the MUF values tend to be consistently negative, one would suspect biased measurements or recording mistakes.[11] Of course, the biggest concern is statistically significant positive MUF values bigger than the LEMUF because this could indicate diversion, loss, or theft.

The inventory difference also has to reconcile losses of uranium and plutonium through radioactive decay and transmutations of an element to a different element in a nuclear reactor or accelerator. Other losses or consumptions of nuclear material occur in nuclear explosives or reactors via fission. The DOE has tried to take into account these natural and man-made losses and consumptions in its historical assessment of uranium and plutonium stockpiles, which are discussed later.

Each site that contains, handles, or transfers nuclear material has to maintain a ledger to account for inventories, receipts, and removals. A site that has an appreciable amount of material usually is subdivided into more manageable areas with smaller amounts

of material. These areas are termed Material Balance Areas (MBAs). An MBA is a well-defined physical area, for example, a storage vault for HEU or plutonium. Ledgers are used to track the material stored or used in an MBA and going into and out of an MBA. In effect, a ledger is like a checkbook. Each ledger for each MBA for a total site is summed periodically to determine whether the inventory balances or has differences. The MBA ledger data are sent to the national nuclear database system.

This explanation, which is the typical description one can find at government websites, for example, in the United States, United Kingdom (UK), and Canada, could not convey the difficulties in making accurate measurements, at the first reading. The uncertainties are much greater than one could imagine if one does not understand the problems in measuring several tons of nuclear material moving through bulk production and processing facilities such as large uranium enrichment and reprocessing plants. These problems have resulted in substantial uncertainties in accounting.

The United States used the gaseous diffusion method to enrich practically all of the uranium for military purposes. (During the Manhattan Project, there was some use of the electromagnetic separation and thermal diffusion methods.) The U.S. gaseous diffusion plants were immense, with thousands of diffusion barriers and miles of labyrinthine networks of pipes, pumps, and other machinery. For example, the Portsmouth Plant being decommissioned in Piketon, OH, takes up about 3,700 acres of land and has almost 200 football fields' worth of floor space in buildings for diffusion and other processing of enriched uranium.[12] During these plants' operations, enriched

uranium would easily get stuck in the plants' interiors. Given the history of U.S. production of enriched uranium as discussed earlier, one has to realize that tens of thousands of tons of uranium hexafluoride gas were pumped through these plants to produce the approximately 750-MT of HEU for military purposes. It is not surprising, then, that a few metric tons are considered MUF.

But the accounting problem for tracking HEU was even worse during the decades of massive production. According to the Government Accountability Office (GAO), records were often destroyed due to records disposal instructions, or available recorded data were insufficient to assess how much material could be missing. Concerning the latter issue, the MUF for different enrichment levels was not analyzed for many major facilities during the heyday of production. Thus, one could not say how much material was unaccounted for at the 20 percent enrichment level versus the 90 percent level. (The former is just at the dividing line for HEU, and the latter is weapons-grade material and obviously of grave concern.) According to the GAO, DOE tried to reconstruct data by interviewing contractors who had worked at those sites; consequently, DOE had to rely on the memories of individual workers. At best, DOE could only determine rough estimates of the MUF at those sites. GAO assessed in 1978 that:

> it was extremely difficult for DOE management to routinely analyze the data **from an effective safeguards point of view** without conducting a detailed review of the contractors' inventory records at the facility. The agency recognized this need and in April 1977 began to require contractors to provide the necessary data for such analysis.[13] [Emphasis added.]

From the early-1940s to early-1977, DOE officials and their predecessors in the Manhattan Project and the AEC did not have an effective capability within their accounting systems to know if significant quantities of HEU were being diverted from production facilities.

Plutonium production had a different but equally demanding set of problems in permitting accurate determination of MUF. To make plutonium, reactors convert uranium-238, the very abundant nonfissile isotope of natural uranium, to plutonium-239 by having each uranium-238 nucleus absorb a neutron and then undergo two radioactive decays. Within a few days, a freshly fueled reactor will produce appreciable amounts of plutonium. (Typically, one gram of plutonium is generated for every 1 day of operation at one megawatt (mw) of thermal power. For example, a 1,000-mw thermal power-rating reactor would produce 1,000 grams or 1-kg every day.) To produce weapons-grade plutonium, which contains more than 94 percent plutonium-239, the reactor's irradiated fuel is off-loaded within a relatively short period of a few months. Letting the fuel stay in the reactor longer will result in production of undesirable isotopes such as plutonium-240 and plutonium-241.

With respect to MUF, the important point is that there is relatively rapid loading and unloading of nuclear material from these reactors, and the emphasis was on rushed production during the Cold War. During much of the period of U.S. plutonium production, computer calculations of the reactor's nuclear reactions were done to estimate the amounts of plutonium produced in each reactor rather than measuring the actual amount in each batch off-loaded. These calcula-

tions were one of the major sources of error in determining MUF. The MUF estimate was determined by using the following formula:

> MUF = Input (reactor physics calculation) – Output (to Plutonium Finishing Plant) – Waste (rough sample only) – DVessel inventory

According to a Defense Nuclear Facilities Safety Board report from 1993, the input term was the most difficult to determine and was prone to significant errors.[14] Despite the fact that several independent analyses indicated that the reactor calculations were prone to errors that would overstate the plutonium input, these calculations were used until the early-1970s. However, to try to correct for these known problems, there were some corrections made to the codes in 1961 and 1965, but other errors continued to overestimate the amount of plutonium produced. The result was that there were erroneous increases in MUF. Once a more accurate measurement system was instituted, the MUF tended to decrease by almost an order of magnitude.

The other term that was a source of major error was DVessel inventory, which measured the change in the reprocessing plant's plutonium in its vessels before and after a reprocessing campaign. The best way to calculate this value was to do a system flush after a campaign. Of course, that meant that during the campaign itself the system's operators and safeguards inspectors would not have an accurate accounting. As the Defense Nuclear Facilities Safety Board report highlights:

> On at least one occasion, in trying to determine the cause of a MUF in excess of 40-kg in 1969, all of the

vessels, sumps, and catchbasins were flushed and inspected: total plutonium yield was less than 10 percent of the MUF.[15]

Unfortunately, these were not the only major problems in accurately accounting for nuclear material. As mentioned earlier, discharges of nuclear material in waste streams and the environment were most likely the major reasons why the MUF values were 2.4-MT for plutonium and 3.2-MT for HEU. As also noted earlier, DOE corrected in 2012 its earlier 1996 plutonium inventory report to decrease the plutonium inventory difference by 0.4-MT to account for material determined to be discarded to waste or the environment. In an independent scientific assessment in 1996, Dr. Thomas Cochran investigated plutonium inventory differences at the Rocky Flats Plant and documented numerous instances of significant MUF throughout the decades of operation of the plant. As he underscored, "The very existence of a significant MUF should trigger immediately an investigation as to its cause."[16] He pointed to a declassified study by L. Zodtner and R. Rogers in 1964 that assessed that "losses [of plutonium] have occurred almost every month, and exhibited large variations which may possibly have been due to inventory error."[17] They discussed, for example, a fire in 1957 that most likely resulted in the loss of about 6-kg of MUF. But even much bigger causes of MUF totaled almost 580-kg of "explained" losses. The unexplained losses were still about 84-kg, enough for approximately 20 nuclear bombs depending on the sophistication of the bomb design.[18] (This study was published in early-1964; Cochran details even more losses in his 1996 report.) While more recent studies of Rocky Flats have further explained much of these

previously "unexplained" losses (as documented in DOE's 2012 report), there is still more than 2-MT of plutonium MUF associated with the U.S. fissile material inventory.

As the DOE admitted in its 2012 plutonium inventory report, uncertainties remain:

> about how much plutonium was actually produced, processed, and discarded to waste, especially for the period from the mid-1940s to 1970 before advances in nuclear material measurement systems and computer-aided tools to assist in the analysis of nuclear material accounting data. The uncertainties are reflected in the 2.4-MT cumulative inventory difference. This uncertainty applies especially to waste estimates, where quantities will continue to change and evolve as waste processing and characterization are performed as part of environmental cleanup activities.[19]

Similar uncertainties have greatly complicated the ability to ascertain the amounts of HEU and uranium-233 produced, processed, and discarded to waste.

## THE EVOLUTION OF U.S. MILITARY NUCLEAR MATERIAL CONTROL AND ACCOUNTING SYSTEMS

Given the problems as outlined, how did the United States act to try to solve them? What are the differences between the material control and accounting systems prior to the early-1970s and today? Have there been significant improvements?

From the early- to mid-1940s, mostly during the Manhattan Project era, records were kept in manual form, and there was no standardization of accounting across facilities. In 1948, the first standard proce-

dures were developed, which served as a prototype for the Nuclear Material Information System (NMIS). NMIS was developed because, in the early-1960s, the AEC hired Stanford Research Institute to perform a feasibility study for an improved system. The authors of the study advised creation of a central database with application of statistical techniques to evaluate shipper-receiver differences, book physical inventory differences, and list unaccounted for materials. NMIS began data collection in 1967.[20]

There is a noticeable improvement in the pre-1968 MUF and the post-1968 MUF for HEU. According to the *Striking a Balance* report, before 1968, there was 269-kg U-235 MUF, and total MUF of all commercial sites was 995-kg. (As discussed later, a large quantity of HEU was unaccounted for at the Nuclear Materials and Equipment Corporation [NUMEC] facility prior to 1968.) In comparison, after 1968, there was 76-kg U-235 MUF, and the total of all commercial sites was 549-kg.[21] Most likely the improvement in accounting systems helped decrease the MUF. But importantly, one needs to recognize that after 1968 the United States had substantively ramped down production of fissile material for military purposes. However, there was still handling of many tons of fissile material for the next couple of decades to the end of the Cold War. Since then, there has been a ramp up on the dismantlement side of handling material as the United States has disassembled thousands of warheads as a result of arms reduction agreements with Russia.

In 1976, NMIS was renamed and became the Nuclear Materials Management & Safeguards System (NMMSS). DOE and the Nuclear Regulatory Commission jointly managed this new system. (These two agencies had shortly before been created from the AEC

in order to separate the promotional and regulatory aspects of nuclear power.) NMMSS requires monthly reports per site and semiannual and annual reconciliations. About 250 checks are done in the software to assess the veracity of the data.

In the late-1970s, the NRC identified many potentially serious accounting problems. Sidney Moglewer, an official in NRC's safeguards division, put the matter starkly and provocatively: "Would you rather put your money in a bank with a battalion of guards and a sloppy accounting system, or would you choose a bank with a few guards and good accounting?"[22] He and other NRC staffers reported concerns that the accounting system was ineffective and gave "little confidence . . . that [it] would catch a skillful fuel thief."[23] The NRC's investigation found that the inventory difference exceeded the limits of error about one-third of the time but indicated that was above the business-as-usual rate of 5 percent. The NRC staff's investigation concluded that sloppy accounting was partly to blame, as well as the procedures to measure the limits of error had become inconsistent and "the entire decision structure that's in the current regulations has essentially no statistical basis at all."[24] While the NRC worked on needed upgrades, a couple of commissioners at that time expressed their concern that one of the main culprits for these inventory differences, or MUF, was at one or two facilities that handled naval fuel. In particular, Commissioner Victor Gilinsky said, "You've got some old plants that are not set up to measure things accurately, and they happen to supply fuel for the Navy."[25] Another commissioner on background identified the primary problem facility as the Nuclear Fuel Services Plant in Erwin, TN, which then was the main supplier of fuel for naval submarines. It

would routinely have MUF values of about 1-kg per month. Because the Navy needed the fuel, the government's accountants let this facility continue making fuel despite the large values of MUF.[26]

DOE's Office of the Inspector General also performs inspections of DOE facilities to check on the effectiveness of the accounting system. In addition, the GAO conducts its own assessments of aspects of DOE's material control and accounting system. Here is summarized some important findings from past DOE inspector general and GAO reports.

In a 1978 report, GAO noted "the inability of material accountability systems to accurately measure and account for all nuclear materials in a timely manner because of state-of-the-art limitations and the need for tighter physical security requirements" and that these findings were also identified in July 1976 and May 1977.[27] The 1978 report also found:

> Changes in reported MUF data only underscore the imprecision and subjective judgments involved in accounting for MUF. Authorities believe that MUF is attributed to measurement biases and unmeasurable material held up in equipment, nevertheless no one can be certain of the actual location of the unaccounted for materials.[28]

A more recent GAO report from 2011 assessed the U.S. Government's ability to account for, monitor, and evaluate the security of U.S. nuclear material overseas and found that "nuclear cooperation agreement terms . . . do not stipulate systematic reporting of such information, and there is no U.S. policy to pursue or obtain such information." Moreover, "DOE and NRC do not have a comprehensive, detailed, current inventory of U.S. nuclear material . . . overseas that in-

cludes the country, facility, and quantity of material." Furthermore:

> [n]uclear cooperation agreements do not contain specific access rights that enable DOE, NRC, or State to monitor and evaluate the physical security of U.S. nuclear material overseas, and the United States relies on its partners to maintain adequate security.

Finally, "[o]f the 55 visits made from 1994 through 2010, U.S. teams found that countries met international security guidelines approximately 50 percent of the time."[29]

The DOE inspector general has issued several reports detailing lapses in accounting for nuclear materials. In an October 2001 report, the inspector general identified that DOE could not fully account for nuclear materials loaned or leased to domestic licensees, at least partly due to inaccurate and/or incomplete NMMSS record keeping.[30] In a February 2009 report, it found:

> For about 37 percent (15 of 40) of the domestic facilities we reviewed, the Department could not accurately account for the quantities and locations of certain nuclear materials. In a number of cases, the Department had also agreed to write-off large quantities without fully understanding the ultimate disposition of these materials. . . . During 2004, a number of domestic licensees reported that their actual holdings of Department-owned nuclear materials were less than the quantities recorded in NMMSS. Based on that information, the Department agreed to write-off over 20,000 grams of special nuclear material . . . without investigating the whereabouts or actual disposition of the material. . . . A 32 gram plutonium-beryllium source on loan to a college and subsequently transferred to another academic institution was not accounted for in NMMSS.[31]

While these problems are serious, the materials in question were not identified as significant amounts of category I nuclear material, which can be directly used in nuclear explosives. Nonetheless, improvements are needed within the management and accounting systems.

Concerning improvements, the 2009 inspector general's report recommended conducting a confirmation of balances of DOE-owned materials and establishing a schedule for periodic confirmations, reconciling this information with NMMSS data, periodically confirming the continuing need for DOE-owned nuclear material at domestic licensees, and improving training. The GAO's 2011 report recommended:

- Determining a baseline inventory of weapon-usable U.S. nuclear material overseas; establishing procedures for annual reconciliations.
- Facilitating visits to sites that U.S. physical protection teams have not visited that are believed to hold category I material.
- Seeking to include physical protection access rights in new or renewed nuclear cooperation agreements. Careful consideration should be given to the impact of any reciprocity clause on U.S. national security.
- Developing an official central repository to maintain data regarding U.S. inventories of nuclear material overseas.
- Developing formal goals for and a systematic process to determine which foreign facilities to visit for future interagency physical protection visits.
- Periodically reviewing performance in meeting programmatic goals.[32]

A very recent DOE inspector general's report raises concerns about the Los Alamos National Laboratory's accounting system that illustrates that even 98.34 percent accuracy is insufficient; the number of errors found showed that the accounting system fell short of its target objective of 99 percent accuracy.[33] This inspector general's report is a follow-up to the September 2007 report on weaknesses found at Los Alamos' accounting system. The July 2013 report found that while the "materials in question were relatively small and the control and accounting issues did not involve materials in sufficient quantity, enrichment and/or configuration to pose a high level of risks," these "issues were, however, worthy of correction and could enhance accounting of higher security category nuclear materials."[34] One of the biggest findings was that "it was standard practice for Los Alamos Materials Control & Accountability (MC&A) Group personnel to conduct inventories in the MBAs we reviewed only on a biennial basis," which raised the concern that "this periodic oversight was not sufficient to ensure MBA inventory control and accounting concerns were identified and addressed in a timely manner."[35]

An independent assessment a couple of years ago by Jonas Siegel of the University of Maryland also highlighted concerns about the effectiveness of the NMMSS. He pointed out that NMMSS:

> relies entirely on facility-level systems to provide detailed, accurate accounting data in a timely fashion . . . varying levels of detail leave significant gaps in what U.S. officials know and can report about U.S. materials; . . . data submitted to NMMSS doesn't always distinguish between what material is in which material balance area within a facility; it doesn't always accurately reflect the location of in-transit materials;

and changes in inventory aren't always reported in a timely fashion.[36]

## INSIDER THREAT

The biggest security concern often comes from those who know nuclear facilities best: employees and management. They have privileged access and, if managers, have authority to coerce subordinates. Thus, insiders have means and opportunities; it will just take motivations to push insiders to exploit vulnerable security systems. According to the National Nuclear Security Administration (NNSA):

> Almost all known cases of theft of nuclear material involved an insider. . . . Even when the insider's illicit activities are observed by coworkers, they often go unreported due to the unwillingness of many workers to recognize the potential for an insider threat and to report on a colleague or especially a boss if a supervisor is the insider thief.[37]

A RAND study from 1990 found that insider/outsider collusion is most relevant to potential crimes targeting nuclear assets. Most of the insiders profiled in the RAND study (focused on conventional crimes given the paucity of data on nuclear crimes) were motivated primarily or solely for financial gain. This finding suggested to the RAND researchers that an outside group "could secure an insider's assistance simply by paying him or her."[38] Perhaps this report's "most important finding" is that success of the criminal operation "seemed to depend less on detailed planning or expert execution than on the exploitation of existing security flaws." The RAND report, however, emphasized, "none of the organizations in our

database employed security equivalent to that at a nuclear facility."[39]

The RAND study also found that guard forces pose a "particularly vexing problem"; specifically, guards "were responsible for 41 percent of the crimes committed **against guarded targets"** [emphasis in the original]. Guards obviously know the security routines and can exploit times when supervisors may not be watching or checking up on the guards.

In addition, the RAND report highlights motivations other than financial gain, including "family ties, misplaced altruism, and ideological allegiances." It cautions that:

> security considerations in hiring, guarding, controlling, and checking people can become so cumbersome as to impede the operation of the facility they are meant to protect. Therefore, no organization, no matter how ingeniously protected, can operate without some trust in individuals on all levels. . . . Total security can never be attained, nor can insider crime ever be completely prevented. However, security officials can and must keep all possibilities in mind at all times, to avoid surprises and to be prepared at least to minimize damage.[40]

To protect against thefts of nuclear material, the NNSA recommends and implements a multilayered approach. NNSA categorizes these approaches into two areas: administrative controls and policies, and technical systems. For the former, "human reliability programs help identify at-risk employees before they can become a threat." NNSA also highlights nuclear security culture programs that:

> educate employees on the threat, encourage robust procedural adherence and effective management, and help employees understand their personal responsibility for nuclear material security.[41]

While nuclear security culture is important, it is not sufficient to stop a highly motivated insider; in that respect, personnel reliability programs are essential but may still not be enough. Consequently, to further strengthen the multilayered approach to security, technical systems provide access controls, material controls, and detection and delay features.

> Access control systems and material controls can be used to help enforce administrative controls such as the two person rule, compartmentalization of information, and separation of duties. Detection systems identify when an insider violates access requirements, and delay barriers can impede an insider from accessing a target.[42]

An independent assessment from the late-1980s emphasized the importance of enforcing the two-person rule but pointed out that there has been substantial resistance to implementing it.[43]

## THE CASE OF NUMEC AND THE MISSING HEU

Perhaps the greatest alleged incident of insider theft happened in the 1960s at NUMEC, located in Apollo, PA. NUMEC was a nuclear fuel processing plant. In 1965, an AEC inspection at the facility discovered more than 100-kg of unaccounted for HEU. But for several years after this finding, concerns were mounting that the U.S. Government was covering up what happened to the unaccounted for HEU. In part

to address these concerns, in 1977, 12 years after the aforementioned inspection, John Dingell, then the Chairman of the House's Subcommittee on Energy Power of the Committee on Interstate and Foreign Commerce, requested that the GAO investigate the so-called NUMEC affair. Specifically, he asked GAO to concentrate primarily on two questions: 1) What information has been developed about the alleged diversion? and 2) Were the investigations done by the federal government adequate?

GAO reported that it was seriously constrained in its review because it "was continually denied necessary reports and documentation on the alleged incident by the Central Intelligence Agency (CIA) and the Federal Bureau of Investigation."[44] The allegations included:

- The material was illegally diverted to Israel by NUMEC's management for use in nuclear weapons.
- The material was diverted to Israel by NUMEC's management with the assistance of the CIA.
- The material was diverted to Israel with the acquiescence of the U.S. Government.
- There has been a cover-up of the NUMEC incident by the U.S. Government.[45]

The GAO did point out that the government investigations had put pressure to improve the U.S. safeguards program. Indeed, there has yet to be an incident of this alleged magnitude since 1965. Regarding GAO's investigation of the relevant documents from previous investigations:

> GAO cannot say whether or not there was a diversion of material from the NUMEC facility. DOE has taken the position that it is aware of no conclusive evidence that a diversion of nuclear material ever occurred at the NUMEC facility, although it recognizes that the possibility cannot be eliminated.[46]

In addressing Chairman Dingell's key questions, the GAO concluded that U.S. Government agencies' investigations were "uncoordinated, limited in scope and timeliness . . . and less than adequate."[47] Another important finding was that the United States:

> needs to improve its efforts for effectively responding to and investigating incidents of missing or unaccounted for weapons-grade nuclear materials. In view of increasing terrorist activities throughout the world, the ability to respond and investigate such incidents should be of concern to national security and the public health and safety.[48]

In a much more recent article on this alleged diversion, Gilinsky and Roger Matson document that by the early-1960s, there were "worrisome signs" that NUMEC's "security and accounting were deficient."[49] They also pointed out concerns about the chief executive officer's connection to the Israeli government and the visits by Israeli officials and technical experts. While, like the GAO, they note that no direct evidence of a diversion was ever uncovered, they believe, based on their extensive assessment, that "the circumstantial evidence supports the conclusion that the HEU ended up in Israel."[50]

## CONCLUSION: ADEQUACY OF TIMELY WARNING AND THE WILLINGNESS TO ACT

What are "good enough" accounting procedures? Adequate accounting should, at a minimum, give enough warning of a potential theft or diversion of a bomb's worth of nuclear material. As mentioned several times in this chapter, the United States has had incidents where accounting lapses have occurred or an alleged major insider theft has happened. Assuming that thefts or diversions had occurred, the warning signs would have come too late to prevent someone or some group from making any possibly stolen or diverted nuclear material into nuclear explosives. Effective safeguards should deter diversion by raising the risk of getting caught. But if weeks, months, or even more than 1 year can go by without detection, the accounting system is not adequate because in as little as 1 week, a few kilograms of category I nuclear material could be enough to make a nuclear explosive. Nonetheless, as discussed in this chapter, the United States made significant improvements in its accounting system after the 1960s. But as recent GAO and DOE inspector general reports have indicated, the United States still has improvements to make in its current accounting system because it has yet to meet its own standards.

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# CHAPTER 3

# A BRIEF COMMENTARY ON "U.S. MILITARY NUCLEAR MATERIAL UNACCOUNTED FOR: MISSING IN ACTION OR JUST SLOPPY PRACTICES?"

**Thomas B. Cochran**
**Matthew G. McKinzie**

Special nuclear material (SNM) is an integral part of nuclear energy and nuclear weapons, and the primary means for protection of SNM is safeguards. Safeguards address the questions: "Is SNM missing?" and "If SNM is missing, how much is unaccounted for and when did it go missing?" There are two main elements to safeguards: 1) methods of containing and monitoring SNM; and 2) methods of accounting to keep track of SNM quantities and locations. Methods of containing and monitoring SNM are such safeguards as vaults and locks, armed guards, personnel security clearances, and, as we discuss later, the two-person rule. The importance of accounting methods for safeguards is the insider threat to diversion of SNM, where the first category of safeguards could be plausibly bypassed by someone with inside knowledge and access.

Within safeguards, the terms "inventory difference" (ID) and "material unaccounted for" (MUF) are equivalent, and are defined as a "book inventory" of SNM minus the "physical inventory" of SNM, where the book inventory is the quantity of material present at a given time as reflected by accounting records, and the physical inventory is the quantity determined to be on hand by, first, physically ascertaining its pres-

ence, and then using techniques that include measuring, sampling, weighing, and analysis. A central thesis in Chapter 2, "U.S. Military Nuclear Material Unaccounted For: Missing in Action or Just Sloppy Practices?" by Charles D. Ferguson, is that the United States is not currently achieving acceptable standards addressing MUF for defense programs SNM, and if this is true for the United States, then this is likely true for other nuclear weapon states such as Pakistan and Russia.

We agree with the author that in the first decades of the Cold War, inattention to SNM accounting, as well as poor industrial practices, led to large values of MUF in the U.S. nuclear weapons program. Thomas Cochran documented plutonium inventory differences at the Rocky Flats Plant outside of Denver, CO, in a 1996 report:

> It is a shameful legacy of the contractor operations of the Rocky Flats Plant that internal accounting and off-site environmental measurements of plutonium did not receive the attention they demanded from the very start of Rocky Flats operations in 1952. At Rocky Flats the uncertainties in estimated plant releases, reconstructed radiation doses and public health effects, when derived from off-site contamination measurements, are very large. The upper end of these estimates no doubt will be consistent with the very large MUF values at Rocky Flats—that is, with what we do not know about the whereabouts of much of the plutonium. The plutonium release estimates could be increased by orders of magnitude and still be consistent with the MUF.[1]

Today, however, the United States is not producing SNM for nuclear weapons purposes. The U.S. Department of Energy (DOE) site receiving and processing

large quantities of SNM in the form of intact weapons and after disassembly, weapons components, is the Pantex Plant near Amarillo, TX. However, SNM in discrete, countable forms will be amenable to much better accounting than SNM in bulk handling and processing, as was the case during the Cold War where the uncertainties in material accounting were so large that they exceeded the required quantity of material for weapons.

With respect to material accounting at Pantex, little public information exists on the safeguards system used at this site. Two memos from the Defense Nuclear Facilities Safety Board made available on the Board's website[2] described material accountability incidents at Pantex, currently operated by the contractor Babcock and Wilcox (B&W):

> [January 6, 2012]: B&W uses the Pantex Material Move System (PMMS) to authorize all movements of nuclear explosives, nuclear material, certain types of nuclear explosive-like assemblies, and certain types of explosives. A software-based electronic material move system called Move Right serves a critical role in PMMS authorization as it helps to ensure that all moves comply with the material limits specified in the documented safety analysis. B&W recently identified a discrepancy between the quantity of plutonium listed in the Move Right system and the quantity listed in an electronic thermal monitoring system for a particular facility. The discrepancy existed for approximately 1 week before transportation personnel evaluated the physical configuration of the facility and confirmed that the quantity in the thermal monitoring software was correct, and the material was in the correct location. Upon further evaluation, information technology (IT) personnel discovered that a B&W software subroutine that should have updated the Move Right system to reflect the quantities in the thermal monitor-

ing system had not initiated. B&W plans to conduct a cause analysis of the event. IT personnel are performing daily checks to validate the proper function of any software that transfers information between systems that track accountable material.[3]

[September 30, 2011]: This week, technicians were performing nuclear material accountability walkdowns when they discovered a discrepancy between the quantity of nuclear material listed in the electronic material inventory system and the actual quantity of material present in a facility. Manufacturing personnel have identified the facts surrounding the event and determined that a weakness exists in the process that they rely on to ensure that the nuclear material and explosive facility limits specified in the safety basis are not violated. B&W ensures compliance with material limits using a software-based electronic material move system and various independent checks to verify consistency between the material move paperwork, the electronic system, and the actual component. However, once the component has been packaged, technicians are completely reliant on a barcode card (containing the level of assembly, part number, serial number, etc. . . .) as the source of information for the electronic material move system. Several of these cards can be present in a facility at a time since the cards are created and assigned to components and different levels of assembly as a unit transitions through an assembly or disassembly process. This material inventory discrepancy was introduced when technicians inadvertently swapped the barcode cards for different levels of assembly prior to moving an item. The discrepancy has since been resolved. Manufacturing management plans to conduct a formal cause analysis of the event with the objective of identifying corrective actions that would eliminate this vulnerability from the B&W material tracking process.[4]

These examples illustrate that a necessarily complex safeguards system will plausibly have gaps, (i.e., multiple barcode cards), and those gaps could be exploited from an insider threat.

Chapter 2 introduces the reader to the Nuclear Materials Management and Safeguards System (NMMSS), a U.S. safeguards system jointly managed by the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC). Regarding methods of containing and monitoring SNM, the NRC recently shelved consideration of the "two-person rule," a requirement that "two qualified and authorized individuals are present" when working with SNM. As Dr. Ed Lyman from the Union of Concerned Scientists recently observed, the two-person rule is a "requirement that could greatly reduce the insider threat at U.S. nuclear facilities handling nuclear weapon-usable and other sensitive nuclear materials."[5] Regarding methods of accounting within the NMMSS, the statistical analysis for SNM accounting in material balance areas provides critical information for safeguards; however, based on our information, a statistical analysis for SNM accounting are not required reporting within the NMMSS from individual DOE sites. An NMMSS information circular posted online[6] lists monthly due dates for transactions and inventory, roughly 2 weeks following the "Reporting Month."

In conclusion, while serious problems with MUF have been documented for the U.S. nuclear weapons program during the Cold War, the DOE today is not producing SNM for nuclear weapons purposes, and therefore we do not expect this issue to be as significant as it has been in the past. While anecdotal evidence suggests that challenges to SNM safeguards persist at DOE and at NRC, the information required for a full

picture of the state of safeguards in the United States, or in other nuclear weapon states, is not available to the public due to classification of technical data.

## ENDNOTES - CHAPTER 3

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# PART II

## CHAPTER 4

# SOMETIMES MAJOR VIOLATIONS OF NUCLEAR SECURITY GET IGNORED

**Victor Gilinsky**

The traditional justification for accepting nuclear power activities around the world, despite their obvious technological overlap with military ones, is that they are covered by agreements restricting them to "peaceful uses," and that any violations of these agreements would be detected in time by international inspectors or by national intelligence. "In time" means that a violation would be detected early enough so that the international community could use the information to thwart the effort to make bombs.

At this point, all non-nuclear weapon countries are members of the Nuclear Nonproliferation Treaty (NPT), so we are talking about the "safeguards" of the International Atomic Energy Agency (IAEA). The objective of these safeguards is thus to dissuade any would-be bomb makers from even attempting a violation for fear of a swift response. As stated in the basic IAEA safeguards document, the objective is:

> the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons . . . and deterrence of such diversion by the risk of early detection.[1]

## BUT, OF COURSE, THERE IS MORE TO IT

We know that some countries and leaders have been willing to take risks to make bombs, and some

have managed to avoid detection in the first stages of violations. To reduce the chance of such detection failures in the future, there are frequent policy suggestions that we spend more money on IAEA safeguards and on national intelligence to improve **detection**. Israel, India, and Pakistan never joined the NPT, but their bomb making involved violations of other nuclear-related agreements and understandings, and failures to detect these played a role in the ability of these countries to finesse international opprobrium.

But, of course, there is more to deterring violation of agreements than assuring detection. The IAEA's safeguards factsheet takes a realistic view—it says effectiveness in stifling proliferation as it relates to nuclear energy activities depends on three things: awareness of all nuclear activities in the various countries (to eliminate the possibility of clandestine facilities), physical access for inspectors to check on materials, and the "will of the international community . . . to take action."[2] All are important, but the last, enforcement of the rules, is key, and it is the hardest to assure.

U.S. President Barack Obama underlined the need for firm international enforcement of nuclear rules in his 2009 Prague speech:

> We need real and immediate consequences for countries caught breaking the rules . . . Some countries will break the rules. That's why we need a structure in place that ensures when any nation does, they will face consequences.[3]

He was talking about the NPT, but the suggestion applies more broadly to security agreements and laws and understandings with the three non-NPT states—India, Israel, and Pakistan.[4] The trouble is, even when solid information on violations is available early

enough, the main countries on whose action international enforcement depends are sometimes reluctant to take needed action. If they do not, however, if there is no sure and swift response, then there is also no sure deterrence for subsequent events.

## THE WILL TO RESPOND IS NOT A SURE THING

It is a familiar phenomenon in ordinary life that a friend of a violator of the law, or even a victim, is reluctant to report a crime. It also happens on an international level in dealings between states. It is natural, understandable, and difficult to rule out, however much of it undermines the rule of law. It suggests, therefore, that the seemingly plausible theories on how international safeguards would work if we only had adequate intelligence are just that, theories, and cannot be entirely relied upon in practice.

The example I want to concentrate on is the failure of the United States to react to the theft by Israel of highly enriched uranium (HEU) from a U.S. plant in Apollo, PA, in the mid-1960s. Aside from being an abuse of what friendly countries expect of each other, it was a flagrant violation of the U.S. Atomic Energy Act that could have subjected the perpetrators to the death penalty. I will explain in some detail why the conclusion that the Israelis swiped the material is in the beyond-a-reasonable-doubt category.

In 2010, I co-authored an article about the affair in the *Bulletin of the Atomic Scientists* that pointed strongly to Israel as the guilty party.[5] I got lots of e-mail in response to the article, including from people who had held high positions in the nuclear world. No one ever wrote to me questioning the conclusion.

The Apollo theft is not the only such case in which the United States ignored a grave proliferation-related violation by Israel. Perhaps the most important such case involved Israel's 1979 bomb tests off South Africa.[6] These tests violated the Limited Test Ban Treaty, of which Israel is a party. But the story that fits best with the material accounting theme of this book is the event at Apollo.

## FEIGNING IGNORANCE TO AVOID RESPONDING

For obvious reasons—the strong support Israel has in domestic U.S. politics—the country is a special case when it comes to any U.S. governmental action. So it is not surprising that the U.S. Government was not inclined to take tough action in response to the disappearance of HEU at Apollo. This policy of feigning ignorance about nuclear violations when it was inconvenient to mention them was not, however, restricted to Israel. For different reasons, the United States also looked the other way at serious bomb-related violations in India, Pakistan, and North Korea.

When Congress started asking questions about possible U.S. involvement after India's 1974 bomb, the State Department presented misleading heavy water accounting to make it appear that there was no such involvement. In fact, India produced the plutonium for its bomb in its Canadian-Indian Reactor, U.S. (CIRUS) reactor, using American-supplied heavy water. The State Department never acknowledged that such use by India was a clear violation of the 1956 U.S.-India heavy water contract, which restricted applications to "research into and the use of atomic energy for peaceful purposes."[7] India went on to stockpile CIRUS plutoni-

um for weapons, and thus some fraction of its nuclear warheads use plutonium produced illegally with U.S. heavy water. The United States has taken no notice of this.

Pakistan's nuclear weapons program was also a beneficiary, at a crucial time for it, of what might be called American benign neglect. The executive branch pretended ignorance to an extent of Pakistan's HEU production in the 1980s and maintained that position as long as it could in the face of facts, when the United States thought it needed Pakistani help to fight the Soviets in Afghanistan.

The case of North Korea was rather different in that its 1992 violation of its NPT responsibilities was public and obvious. Pyongyang refused to permit the IAEA inspectors to complete their check of its initial nuclear material declaration upon joining the treaty. In particular, North Korea would not let the agency inspect two waste sites to check whether the country had performed illicit reprocessing, which, of course, it had. North Korea threatened that if the IAEA insisted on the inspection, it would leave the treaty altogether. U.S. and other diplomats were afraid that a North Korean departure from the NPT would threaten the success of the upcoming 1995 NPT Review Conference at which the United States hoped to make the treaty permanent. Of course, if the North—which had a small reactor and reprocessing plant and was building two other reactors—left the treaty, it would be free to turn its facilities to military use. Adding to that was the constantly worrisome presence of thousands of North Korean artillery pieces trained on Seoul, South Korea.

The threats worked, and in 1994, instead of pressing for international sanctions against North Korea for its NPT violation, the United States offered it a

very generous deal in return for staying in the treaty. This deal, known as the Agreed Framework, included shielding the North from any NPT enforcement actions by postponing more or less indefinitely the disputed inspections.[8] In addition, in return for stopping its two nuclear construction projects, the United States offered the North two large U.S.-type light water reactors (LWRs), to be built and paid for by the South Koreans and Japanese, and a generous supply of oil.[9] The deal fell apart at the start of the administration of U.S. President George W. Bush when, in a meeting with a U.S. representative, the North Koreans admitted they had a secret uranium enrichment project.[10] A contributing factor was that it was becoming obvious North Korea did not intend to allow the disputed inspections. The significant result, however, in terms of the NPT, was that the violator's threats forced the United States and other major NPT members to back off.

## IGNORING ISRAELI THEFT OF HEU IN 1960s

To return to the principal subject of this note, in the mid-1960s, the Apollo Plant, which had been processing large quantities of HEU fuel for the U.S. Government, could not explain the loss of about 100 kilograms (kg) of HEU. The plant was operated by the Nuclear Materials and Equipment Corporation, which was known as NUMEC. The loss, and some of the circumstantial evidence known at the time connecting NUMEC's owners with Israel, caused considerable consternation within the U.S. Atomic Energy Commission (AEC), the agency that licensed the activity. Difficult as it is to believe, the loss was never investigated in a comprehensive way by the AEC or the Federal Bureau of Investigation (FBI), which had responsibil-

ity for investigating criminal violations of the Atomic Energy Act. The Central Intelligence Agency (CIA), on a separate and independent track, took an interest in the case as it related to the interest in Israel's secret nuclear weapons program and came to believe the missing HEU ended up in Israel.

The whole affair was enveloped in secrecy and, while there was some reporting in the press, the key documents did not, and have not, seen the light of day. At least four U.S. presidents—Lyndon Johnson, Richard Nixon, Gerald Ford, and Jimmy Carter—were aware of the case and kept it under wraps, and it has stayed that way.[11]

## WHAT DOES "COULD NOT EXPLAIN" MEAN?

A word is in order on what it means that the loss of HEU "could not be explained" (the usual term of art is "material unaccounted for" or MUF). The Apollo Plant's overall loss of HEU during material processing was in fact much larger than the approximately 100-kg reported in 1965. The plant and AEC understood that there were certain natural loss mechanisms, including escaping gases, fluids, material stuck to piping and equipment, etc., which were estimated and subtracted from the total loss. As they were both interested in minimizing the announced losses, we can be sure both NUMEC and the AEC assigned generous amounts to these loss pathways in the original inventories. The unexplained loss was what remained after all these possible process losses had been subtracted from the overall loss.

Over the couple of years after 1965, another loss of 100-kg could not be explained, so there remained in all about 200-kg total unexplained. Unexplained losses

were common in the industry, but NUMEC's losses were an unusually high percentage of the throughput while the original NUMEC management operated the plant (which continued for a time after the plant was sold to Atlantic Richfield in 1967). DOE's 2001 report stated that Apollo's cumulative HEU loss from the start of operations in 1957 through 1968 was 269-kg of uranium-235, including the approximately 100-kg that was missing in 1965. It also reported that only 76-kg was unaccounted for in the period from January 1969 until 1978, including the 8 years that Babcock & Wilcox (B&W) ran the operation, during which the plant's HEU "throughput" increased substantially. Records from the time indicate that losses of HEU in the 10 years of operation through 1968 exceeded 2 percent of HEU throughput, while losses in the 10 years after 1968 were less than 0.2 percent of throughput.

But there was more than simply material accounting to the concern that the missing material was stolen.

## WAS THE MATERIAL EVENTUALLY FOUND?

I have first to clear away the oft-repeated claim that the missing "100-kg" of HEU was recovered when the Apollo Plant was taken apart. Seymour Hersh, in *The Samson Option*, wrote that the missing "100-kg" HEU was recovered when the Apollo Plant was taken apart.[12] Beginning in 1978, B&W, which bought the plant from Atlantic Richfield, did carefully dismantle Apollo, recovering HEU containing 95-kg of uranium-235 from equipment and structures, and estimating that another 31-kg was left unrecovered in the concrete floor and walls, for a sum of 126-kg.

But the cumulative MUF—the unexplained missing amount—for the entire 1957-78 period of HEU operations at Apollo was 463-kg. That leaves 337-kg as the cumulative amount of HEU still unaccounted for—more than three times the MUF in the 1965 inventory. In other words, the fact that about 100-kg of uranium-235 in the form of HEU was found during post-1978 decommissioning does not bear on whether the 100-kg that AEC could not account for in 1965 inventory, or the larger amount that went missing during the 1966-68 period, was diverted.

In fact, some or all of the material recovered during dismantling may have already been in the "accounted for" category, that is, already included in the normal industrial loss category. That would already have been subtracted from the total loss, and it made no sense to subtract it again. In any case, the conclusion stands that: The found 100-kg does not bear on whether there was a diversion.

## REASONS TO BELIEVE ISRAEL SWIPED HEU

This brings us to the various elements of circumstantial evidence that the unusually high unexplained HEU losses while under NUMEC management point to thefts by Israel. The potentially most dispositive evidence is the reported CIA claim that, around 1968, it obtained environmental samples in Israel of HEU that match the HEU output of the Portsmouth uranium enrichment plant. Portsmouth produced fuel of higher enrichment than any other enrichment plant in the world. If the environmental samples taken in Israel were significant enough to identify this ultra-high enrichment, it would be a firm indication that the missing NUMEC HEU ended up in Israel. It was ap-

parently this data that convinced the CIA that its earlier suspicions about NUMEC were correct. The problem from our point of view is that the basic documents remain highly classified, and all we have are various reported conversations about the environmental samples that made it into the public domain. In any event, the CIA's conclusions drew attention to NUMEC.

The NUMEC plant was owned and managed by a group with close Israeli ties. The company president, Zalman Shapiro, met frequently with Israeli scientific attachés, who were obviously intelligence agents, and he gave evasive and contradictory responses about these meetings. He also visited Israel frequently. He admitted meeting with the head of Israeli military intelligence and knowing the head of LAKAM, the secret scientific intelligence agency that conducted daring operations.[13]

Israeli intelligence was obviously aware of the opportunities NUMEC's loose material accounting offered to snatch HEU for Israel's weapons program. During the early- to mid-1960s, Israel did not yet have plutonium from its Dimona reactor. HEU would have been a highly sought after commodity. It was, of course, a nuclear explosive and could be used in warheads. It could also serve as driver fuel to increase the power of the Dimona reactor and thus increase plutonium production. Israeli intelligence, especially LAKAM, had a stop-at-nothing approach to further Israel's nuclear weapons program, did not let opportunities slip, and was accustomed to taking big risks.

One might at first think that, however daring the Israelis, they would hesitate to run an illegal diversion of HEU at NUMEC because of the obvious risks. That thought should have been put aside after the elaborate Jonathan Pollard spying operation during

the mid-1980s, in the course of which, in a specially outfitted house in Potomac, MD, Israel stole and copied thousands of highly classified U.S. intelligence documents. The Israelis then did not cooperate with the U.S. investigation of the case. In a book about the Pollard operation, Wolf Blitzer wrote:

> . . . a widely held attitude among Israeli officials that Israel can get away with the most outrageous things. There is a notion among many Israelis that their American counterparts are not too bright, that they can be 'handled' thanks partially to the pro-Israel lobby's clout in Congress.[14]

NUMEC was a commercial agent for Israeli government agencies. It also was in a partnership with Israelis ostensibly to develop technology to irradiate fruit to eliminate insects. The partnership was called ISORAD, and the small board at the Israeli end included the chairman of the Israeli Atomic Energy Commission, almost all of whose effort was devoted to weapons. Under the ISORAD rubric, NUMEC sent large shipments to Israel. These were large enough to cover shipments of illicit HEU. At the time, there were no government controls over such shipments. Nor did the AEC keep track of the amounts of nuclear materials exported; it relied on commercial firms to maintain their own records. According to FBI interview reports, NUMEC delivered a 600-pound package, listed as containing neutron sources, to El Al Airlines in December 1963. The AEC's 1965 inventory showed that more HEU went missing from the Apollo Plant in 1963 than any other year.[15]

Former NUMEC employees also told FBI agents about strange truck shipments in the 1960s that went directly to Israeli ships docked in the New York area.

One recalled an unusual truck loading what looked to be HEU containers from the plant one night in 1965 or 1966. He said that an armed guard ordered him to leave the area. Others claimed to have been threatened by NUMEC managers to keep quiet about what they saw at the loading docks. It is difficult at this point to assess these accounts. The FBI does not appear to have followed up, which is a significant example of how obvious violations sometimes get handled in a politically charged case. Of all of the various aspects of the Apollo affair, the one I find the most intriguing involved the 1968 visit to the plant of high-level Israeli agents, men used to running complex illegal operations, with false identities.

## ISRAELI QUARTET 1968[16]

In September 1968, four Israeli visitors arrived at Apollo, supposedly to discuss small plutonium 238 power sources NUMEC was developing.[17] NUMEC had to get AEC permission for the foreign quartet to visit the Apollo facility and so had to identify them. Their guide was Avraham Hermoni, scientific counselor at the Israeli Embassy in Washington, and a frequent visitor to NUMEC. The others were listed as Rafael Eitan, chemist, Ministry of Defense, Israel; Avraham Bendor, Department of Electronics, Israel; and Ephraim Biegun, Department of Electronics, Israel. Hermoni identified himself correctly. But no one in the AEC security apparatus seemed to know that he had been technical director of Israel's nuclear bomb project at Rafael, Israel's armament development authority. As scientific counselor, he surely reported to LAKAM. The others falsified their affiliations.

Eitan was not a chemist; he was a high-level, highly experienced Mossad agent who headed the team that captured Adolf Eichmann in Argentina in 1960. In later years, Eitan became an adviser to Israeli Prime Minister Menachem Begin and, in 1983, took charge of LAKAM, the scientific intelligence agency, in which role he ran the Pollard spying operation in the 1980s. No one seems to have asked what a top intelligence operative like Eitan was doing at the Apollo Plant in 1968 or why he lied about his affiliations.[18] It is impossible to believe that the president of NUMEC, who had very close Israeli ties, including ties at the top level of Israeli intelligence, did not know Eitan's identity. Yet NUMEC passed on the false information to the AEC.

With Eitan was Avraham Bendor, who was not affiliated with a Department of Electronics; there was no Department of Electronics. His real name in Israel was Avraham Shalom (Bendor was his name before he immigrated to Israel). He was a long-time Shabak agent and served as Eitan's right-hand man in Eichmann's capture, in charge of logistics, that is, getting Eichmann from a safe house past airport guards onto an Israeli plane. He became the head of Shabak in 1981 but was forced to retire in 1986 after he ordered, and then covered up, the deaths of two Palestinian prisoners; in short, a tough character.[19] He was not exactly the kind of person you would send to evaluate plutonium batteries, the supposed purpose of the mission to Apollo, but he would be the right man for figuring out how to move material offsite.

The third man, Ephraim Biegun, was the head of the Mossad's Technical Department.[20] Hermoni, of course, knew the trio's real identities, which meant that he, as an accredited Israeli diplomat, not only

participated in, but more likely orchestrated, the lie to U.S. authorities. There is no indication that anyone in AEC security grasped who these visitors really were.

## HOW COULD THIS BE IGNORED?

It would be natural to assume that all these events have been thoroughly investigated by the AEC, the FBI, congressional committees, the White House, and the CIA. In fact, difficult as it is to believe, as we shall see, they were not. What is interesting for our purposes are the multiple ways in which bureaucratic politics, domestic politics in general, and international interests combine to submerge information about issues of genuine national security importance in relation to nuclear proliferation.

After the 1965 discovery that the loss of a large amount of HEU at NUMEC could not be explained, the main concern of the AEC commissioners, led by Chairman Glenn Seaborg, was not that someone made off with it, but that, if the matter became public, it would bring criticism of its overall nuclear power program. The AEC was in an embarrassing fix because it had not been doing its job. It had assumed that private firms working with HEU would minimize losses because of the intrinsic value of the material. The Commission licensed exports but did not keep track of what got sent. It had never imagined that material could be stolen and sent abroad.

What it now feared most was the reaction of the members of the powerful Joint Committee on Atomic Energy, the AEC's congressional oversight committee and the ones who really ran the agency. An AEC team questioned NUMEC employees. But the AEC General Counsel's attorney in charge made sure they

did not take any written statements and/or pursue any indication of illegal activity. The commissioners and staff rallied around a story line that dismissed the possibility of any criminality.

This position was essential to talking the FBI out of entering the case, because the FBI was charged with investigating criminal violations of the Atomic Energy Act. As it turned out, the FBI Washington Office, for its own bureaucratic reasons, did not seem eager to get involved, perhaps because it saw material accounting as a technical issue in which it lacked competence. In any case, the FBI focused on the question of whether, in view of NUMEC's function as an agent for Israeli government agencies, its president, Zalman Shapiro, should have registered as a foreign agent.

Unlike the FBI, the CIA, coming to the case from its interest in Israel's rapidly moving nuclear weapons program, **was** interested in NUMEC as a possible source of HEU for Israel. By 1968, on the basis of information obtained in Israel, the CIA was convinced that Israel had HEU and that it came from NUMEC. But the CIA was not permitted by law to conduct a domestic investigation. In April 1968, CIA Director Richard Helms wrote Attorney General Ramsey Clark a letter (one of the key documents that remain highly classified) suggesting that HEU processed at Apollo might have ended up at Dimona and asked that the FBI investigate.[21] After the memo from the CIA, Clark imposed surveillance on Shapiro, which lasted about a year and produced information on his contacts with Israel that increased concern about NUMEC. Helms informed President Johnson of the CIA's suspicions. Johnson reportedly told Helms, "Don't tell anyone else, even Rusk and McNamara." It was an election year.

## KISSINGER TO NIXON 1969

After he became president, Richard Nixon took an interest in the NUMEC case, but not so much about the missing HEU but rather about Shapiro's connections with Israel. At the start of the administration, the question of whether Shapiro should keep his AEC clearance at one time or another occupied the attention of the Attorney General, the Secretaries of State and Defense, the White House Counsel, the Science Advisor, the National Security Advisor, the AEC Chairman, and the FBI Director.

During 1969, U.S. National Security Advisor Henry Kissinger conducted a secret interagency study on how to deal with Israel's rapid advance toward nuclear weapons. (In truth, Israel had already produced its first nuclear warheads.) In the course of this, and in preparation for an upcoming discussion with Israeli Prime Minister Golda Meir, Kissinger provided a memorandum to the president that included in the "general intelligence judgment" the following: "There is circumstantial evidence that some fissionable material available for Israel's weapons development was illegally obtained from the United States by about 1965."[22]

This what-should-have-been stunning information—a clear reference to NUMEC—obviously came from Helms. Nixon does not appear to have reacted. Perhaps "some fissionable material" does not mean much coming out of the blue. Or perhaps acting on it would have interfered with his plans. He was in the midst of making a deal with Golda Meir in which he would stop the U.S. Government from bothering the Israelis about nuclear weapons, which they were

supposed to keep hidden. In return, he expected them to stand with him in the Cold War and especially in Vietnam, and to get U.S. Jews on board, too.[23] So the NUMEC issue disappeared from sight.

## ISSUE REVIVED IN 1976

The case got revived at the end of the Gerald Ford administration. This came after the U.S. Nuclear Regulatory Commission (NRC, of which I was then a member) asked the CIA to provide a briefing on the NUMEC affair. To everyone's surprise, CIA Deputy Director for Science And Technology Carl Duckett revealed that the CIA believed the missing HEU ended up in Israel.

The White House took an interest in the case. On the basis of his review of the FBI's performance, U.S. Attorney General Edward Levi informed Ford that the FBI had never conducted:

> an investigation into the alleged discrepancy in nuclear materials at NUMEC because it was advised by the AEC that any loss likely was attributable to inadequate accounting procedures, and that there was no evidence or suspicion of a violation of law.[24]

In short, the U.S. Government had never performed a thorough investigation of the loss of enough HEU for perhaps a dozen bombs.

Levi listed several criminal statutes that might have been violated, including some that pointed to the possibility that federal officials concealed the events after the fact. He concluded: "I believe it necessary to conduct an investigation,"[25] which he instructed the FBI to undertake. But Levi was soon out of office, as Jimmy Carter replaced Ford in the White House.

## MARSH (FORD COUNSEL) TO WATSON (CARTER TRANSITION)

During the transition, John Marsh, Counsellor to the President, discussed the NUMEC case with Jack Watson, the head of Carter's transition team.[26] In early-1977, Marsh sent Watson the following Top Secret documents in the case:[27]

1. Helms' 2-page memo to the Attorney General (Clark), with transmittal cover, dated April 2, 1968;
2. Photostat of 2-page letter from J. Edgar Hoover to Helms, dated September 3, 1969;
3. Helms' 3-page letter to the President, dated September 8, 1969;
4. Internal 3-page memo from Duckett to Director of Central Intelligence dated March 21, 1976, with a 7-page Memorandum for the Record, dated March 9, 1972.

These are still the key documents in the NUMEC case and still remain secret. Some information leaked out, and there was a brief flurry of interest in the press. CBS News reporter Mike Wallace even asked Israeli Prime Minister Menachem Begin about it in a *60 Minutes* interview (and, of course, got nowhere). The matter of Israelis stealing bomb material from the United States was an awkward one in the middle of the "peace process" and dribbled away. That was also the fate of the information about the 1979 Israeli nuclear explosion seen in the ocean off South Africa.[28] The FBI continued to conduct interviews of former NUMEC employees, gathering some interesting information, but it all led nowhere.

## WHAT DOES IT MEAN?

Sometimes violators get away with it, even when detected, as all sorts of real world—bureaucratic, political, and international—considerations intrude on the notion that, with only more and better intelligence and evaluation, we can develop a system of safeguards and response that will deter violations of agreements and laws that protect against proliferation.

That is true, for example, if for the United States to respond vigorously to a violation would upset other international plans, as was the case in India. Immediately after the 1974 Indian bomb test, Henry Kissinger cabled the State Department from abroad with instructions not to issue a strong response, as it would interfere with his plans for dealing with Indian Prime Minister Indira Gandhi.[29] From this, it was a short step for the State Department staff to conclude that it would not do to accuse India of violating a contract with the United States.

It also helps a violator if he is seen as vital to carrying out a core U.S. policy. That was the case with Pakistan in the 1980s, when Pakistan's assistance was seen by the United States as crucial to defeating the Soviets in Afghanistan. (And today, if a close and useful ally, say, such as Saudi Arabia, acted suspiciously, would we react as we do against Iran?) The case of North Korea illustrates that you can thwart enforcement in the wake of an NPT violation, anyhow for a number of years, if you can make a credible enough threat against the major countries involved.

The Israeli situation is special. No other country can match the grip Israel has on U.S. domestic politics

or its ability to sway Congress. (The successful lobbying of the Indian American Council in connection with the 2008 U.S.-India nuclear agreement demonstrates that India is learning fast how to mobilize its U.S. diaspora.)

To bring U.S. policy on Israeli nuclear weapons up to date, it is clear that the United States is not remotely ready to confront any possible Israeli wrongdoing in connection with its nuclear weapons. Our government is not even ready to confront the fact of Israel's nuclear weapons, even though every school child knows Israel has them. When newly elected President Barack Obama was asked at his first TV news conference in 2009 whether he knew of any nuclear weapon states in the Middle East, he said he did not want to speculate.[30]

The official U.S. position on nonproliferation as it relates to Israel remains that the subject should not ever be discussed: At the IAEA Board of Governors Meeting in March 2013, under the heading, "Israeli Nuclear Capabilities and the Helsinki Conference on Establishing a Middle East WMD-Free Zone," Ambassador Joseph Macmanus, the permanent U.S. Representative to the IAEA, stated:

> The United States regrets that the issue of Israeli nuclear capabilities has once again been brought before the Board. Unlike other Member States whose nuclear activities are included on this Board's agenda, Israel has broken no agreements under the purview of the Agency.[31]

The operative phrase is, of course, "under the purview of the Agency," which makes a fine distinction that keeps the statement just within the truth. But it also makes it difficult for the United States to be taken seriously by the international community when we

charge other, less friendly countries with violations of the NPT.

Some of the events I described are decades old, but human nature has not changed. It suggests security of nuclear materials useful for bombs—against national appropriation or theft—is not entirely as advertised. More safeguards and intelligence and protection are not necessarily the whole solution. There remains the crucial element identified in the previously cited IAEA factsheet on proliferation: the "will of the international community . . . to take action." As we have seen, given the realities of world politics mixed with domestic considerations, that "will to take action" cannot be taken for granted, and neither can the effective functioning of the entire international nonproliferation apparatus both within and outside the NPT.

## ENDNOTES - CHAPTER 4

1. *The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons*, IAEA Information Circular (INFCIRC) 153, Vienna, Austria: International Atomic Energy Agency (IAEA), June 1972, para. 28.

2. *IAEA Safeguards: Stemming the Spread of Nuclear Weapons*, FS Series 1/02/E, Vienna, Austria: IAEA, available from *www.iaea.org/Publications/Factsheets/English/S1_Safeguards.pdf*.

3. "Remarks by President Barack Obama," Hradcany Square, Prague, Czech Republic, Washington, DC: The White House, Office of the Press Secretary, April 9, 2009, available from *www.whitehouse.gov/the_press_office/Remarks-By-President-Barack-Obama-In-Prague-As-Delivered*.

4. North Korea is in an ambiguous category. It announced its withdrawal from the treaty in 2003. But because it did so while it was in violation of the treaty, it would be more consistent to regard it as a member in noncompliance.

5. Victor Gilinsky and Roger Mattson, "Revisiting the NUMEC Affair," *The Bulletin of the Atomic Scientists*, March-April 2010. I draw mainly on this article for the history of the NUMEC episode.

6. See Leonard Weiss, "The Vela Event of 1979 (Or the Israeli Nuclear Test of 1979)," Presentation at the conference, "The Historical Dimensions of the South Africa's Nuclear Weapons Program," Pretoria, South Africa: December 10, 2012, available from *iis-db.stanford.edu/evnts/7484/Weiss_vela_presentation_12.10.12.pdf*.

7. See "Agreement between the United States Atomic Energy Commission of the President of India," Washington, DC: Nuclear Control Institute, March 16, 1956, available from *www.nci.org/a/1956_d20.htm*.

8. See "Agreed Framework of 21 October 1994 Between the United States of America and the Democratic People's Republic of Korea," INFCIRC 457, Vienna, Austria: IAEA, November 2, 1994, available from *www.iaea.org/Publications/Documents/Infcircs/Others/infcirc457.pdf*.

9. Ironically, the plutonium production capacity of the proposed two LWRs to replace North Korea's indigenous ones was considerably greater than that of all the indigenous reactors North Korea planned to build.

10. Or appeared to. There is some dispute over the correct translation of what they said.

11. The government's response to the possibility of a major violation of U.S. security and law recalls the reaction of the Bishop of Worcester's wife upon hearing that man descended from the apes: "My dear, let us hope that is not true, but if it is, let us pray that it will not become generally known."

12. Seymour Hersh, *The Samson Option*, New York: Random House, 1993. I find the chapter on the Apollo case strange and at odds with the rest of Hersh's book, which is a tough-minded exposé of Israel's nuclear weapons program, and also at odds with Hersh's usual investigatory approach.

13. Wikipedia has the following entry:

> Lekem, (also pronounced 'Lakam') an acronym for ha-Lishka le-Kishrei Mada (Hebrew: until Relations), Bureau of Scientific Relations), was an Israeli intelligence agency headed by spy-master Benjamin Blumberg (1957-81), and by spy-master Rafi Eitan (1981-86). It collected scientific and technical intelligence abroad from both open and covert sources, particularly for Israel's nuclear program.

See, "Lekem," Wikipedia, last modified December 26, 2013, available from *en.wikipedia.org/wiki/Lekem*. The Office was originally set up to provide security for Dimona. Among other things, it organized the successful deception of American official "visitors" who, in line with a U.S.-Israeli agreement, were supposed to check on whether the reactor was part of a weapons program. Blumberg expanded into intelligence, putting his attachés in Israeli embassies and then into procurement, including "stunningly innovative missions to acquire materials for Israel's secret weapon." Dan Raviv and Yossi Melman, *Spies Against Armageddon*, Sea Cliff, NY: Levant Books, 2012, p. 147.

14. See Wolf Blitzer, *Territory of Lies*, New York: Harper & Row, 1989.

15. The AEC inventory results are in a report written by S.T.C. McDowell, Assistant Director for Control, AEC Division of Nuclear Materials Management, "Report of Survey: Control Over Enriched Uranium, Nuclear Materials & Equipment Corp., Apollo, PA, Division of Nuclear Materials Management," Nuclear Materials Management Survey Number DNMM-53, April 6, 1966. The report can be found in the Benjamin Loeb papers, Washington, DC: Library of Congress. Loeb assisted former AEC Chairman Seaborg in writing his biographical accounts.

16. Taken from the Gilinsky-Mattson *Bulletin* article. The information on the names of the Israeli quartet comes from AEC and FBI documents in the Benjamin Loeb papers. Identifying all four was another matter.

17. Plutonium 238 power sources are used in pacemakers, for example. The Israeli visitors were supposedly interested in power sources for use in security fences for Israeli water systems.

18. In a June 2010 Foreign Policy Association blog, columnist William Sweet described the evidence on this as:

> darkly hilarious—for example, reports of visits to the NUMEC plant by the likes of the top Mossad agent who had managed the kidnapping of Eichmann in Argentina, now pretending that he was a mere member of a trade delegation, as U.S. officials looked the other way. He also said he believed the 2010 Bulletin article by Mattson and Galinsky proved the case for Israeli theft 'beyond any reasonable doubt.'

See William Sweet, "What's History and What's Not," Foreign Policy Blogs Network, June 4, 2010, available from *foreignpolicyblogs.com/2010/06/04/whats-history-and-whats-not/*.

19. Shalom discusses his tenure at Shabak, including the episode that led to his departure, in the recent Israeli movie, *The Gatekeepers*, directed by Dror Moreh, 2012, Sony Pictures Classics, DVD.

20. In *ibid*., columnist William Sweet: "In the March-April issue of The Bulletin of the Atomic Scientists, Victor Gilinsky and Roger J. Mattson prove the assertion beyond any reasonable doubt, I believe, . . ."

21. The April 2, 1968, Helms letter is in the Gerald Ford Presidential Library. In a covering note, Helms wrote, "Since the subject matter of this letter is so sensitive for obvious reasons, I would appreciate if you would return it to me when you have taken whatever action you feel appropriate." The CIA has repeatedly refused to declassify the letter, which might say more about the CIA's discovery in Israel of traces of HEU with a Portsmouth signature. In January 1978, Duckett wrote to Chairman Morris Udall of the House Interior Committee to confirm that the CIA's suspicions in 1968 led to the letter from Helms to Clark. See John J. Fi-

alka, "CIA Heads' Suspicions on A-Matter Reported," *Washington Star*, January 18, 1979. (Taken from Footnote 19 of the Gilinsky-Mattson Bulletin article.)

22. Memorandum, Henry Kissinger to Richard Nixon, July 19, 1969.

23. Richard Nixon, *RN: The Memoirs of Richard Nixon*, New York, Grosset and Dunlap, 1975.

24. Justice Department Memoradum, Attorney General Edward Levi to President Gerald Ford, April 22, 1976, available from *www.fordlibrarymuseum.gov/library/document/0067/1563110.pdf.*

25. *Ibid*.

26. The title was spelled with two ls.

27. Memorandum, John Marsh to Jack Watson, February 8, 1977.

28. In some ways, this event, which the White House tried to pass off as the result of tiny particles hitting the satellite detector in a way that made it think it saw an explosion, is even more important than the NUMEC event. It was likely part of a series of Israeli tests of thermonuclear designs. I have not included it in this account because it does not fall within activities that were claimed to be peaceful. See Leonard Weiss, "Israel's 1979 Nuclear Test and U.S. Cover-Up," *Middle East Policy*, Vol. 18, No. 4, 2011, available from *www.mepc.org/journal/middle-east-policy-archives/israel-s-1979-nuclear-test-and-us-cover*.

29. Harold Bengelsdorf, conversation with author.

30. Helen Thomas, "Transcript of Interview by Paul Jay," *The Real News*, July 13, 2010, available from *therealnews.com/t2/index.php?option=com_content&task=view&id=31&Itemid=74&jumival=4900*.

31. See Ambassador Joseph Macmanus, "Statement at IAEA Board of Governors Meeting, Agenda Item 8, Any Other Business," Vienna, Austria: IAEA, March 4-8, 2013, available from *vienna.usmission.gov/120306wmd.html*.

# CHAPTER 5

# THE NONPROLIFERATION REGIME AND ITS DISCONTENTS

**Leonard Weiss**

Why is it sometimes difficult to get the members of the United Nations (UN), whether states are parties to the Nuclear Nonproliferation Treaty (NPT) or otherwise, to enforce the international rules and norms designed to prevent the manufacture of nuclear weapons by nonweapon states? In Chapter 4, Victor Gilinsky raises this question in the context of the theft of bomb-grade nuclear materials that went from the plant of a U.S. Navy contractor in Pennsylvania to Israel. He avers that the reluctance to enforce the rule of law stems from political considerations that render the nonproliferation regime much less effective than advertised.

This conclusion should not be surprising, for political considerations have surrounded the entire nonproliferation regime from its inception, including the creation of the International Atomic Energy Agency (IAEA) and its system of safeguards, of which more will be discussed later. But Gilinsky's complaint can be generalized, as he recognizes when he writes: "It is a familiar phenomenon in ordinary life that a friend of a violator of the law, or even a victim, is reluctant to report a crime. It also happens on an international level in dealings between states."[1]

The fact is that getting countries to act in the face of violations of signed agreements or agreed upon norms has been a problem whenever conflicting interests come into play. A particularly egregious example

is provided by the reaction to Germany's violations of the Versailles Treaty that ended World War I. In 1935, when Germany announced that its army would be based on compulsory national service, which was a clear violation of the treaty, Britain, France, and Italy, under the aegis of the League of Nations, held a conference at Stresa, Italy, to decide on a course of action. This resulted in a resolution opposing the unilateral repudiation of treaties, but as British Prime Minister Winston Churchill observed in his history of World War II: ". . . the British representative made it clear at the outset that they will not consider the possibility of sanctions in the event of treaty violations."[2] So Germany went its unmerry way, and the world lost an estimated 50 million people in the succeeding world war.

A more direct forerunner of the enforcement problem described in Chapter 4 occurred soon after World War II when the institutional arrangements that were negotiated for the UN required the existence of a veto in the Security Council precisely to prevent the imprimatur of the UN for actions deemed inimical to the interests of the five permanent members of the Security Council and their allies. When an attempt was made by the United States in its proposed 1946 Baruch Plan to block use of the veto in the case of nuclear related enforcement matters, the Soviet Union objected, and the attempt failed. Of course, the Baruch Plan was a transparent maneuver by the United States to achieve a propaganda victory over the Soviets in the early days of the Cold War and not a serious attempt to find a way to encourage nuclear development without spreading bomb technology. Its failure made it clear that enforcement of nuclear rules was going to have a hard road ahead. The prospects for nuclear develop-

ment, which seemed particularly bright in the aftermath of U.S. President Dwight Eisenhower's "Atoms for Peace" speech, blinded the policymakers on all sides to the difficulties of creating and enforcing effective rules that could prevent proliferation without impeding development. The early history of the IAEA and safeguards deliberations illustrate the problems at the heart of Gilinsky's thesis.

The idea of an IAEA was born as part of President Eisenhower's Atoms for Peace speech on December 8, 1953. The subsequent program that was given the name Atoms for Peace had a number of objectives. It was, among other things: a disarmament tool by virtue of the proposed establishment of a nuclear fuel bank that its proposer thought could have the effect of limiting or reducing the amount of fissionable material eligible for weapons; a marketing tool for creating and boosting a world demand for nuclear energy at a time when the United States was in the best position to profit from it both economically and politically; and a propaganda tool to divert attention away from the barbarity inflicted on Japan and the risk of a future nuclear holocaust in favor of presenting peaceful nuclear energy as a contribution to human society's technological and social betterment.

In reality, the disarmament aspect of Atoms for Peace was illusory as it became clear that the amount of fissionable material in the world, including the Union of Soviet Socialist Republics (USSR), was so substantial that proposed contributions to a uranium bank would have no significant impact on weapons manufacture. Nonetheless, the United States was intent on promoting nuclear energy internationally, and the Soviets realized that such promotion had national security implications for themselves; therefore they

decided to participate in the development of any international institution created to deal with peaceful nuclear applications. The United States was unprepared for the Soviet decision and was surprised when the Soviets agreed to send a delegation to an international conference on nuclear energy planned for Geneva, Switzerland, in August 1955. The United States was further surprised when the USSR agreed to participate in the creation of the IAEA and a technical conference, following the large Geneva meeting, devoted to exploring the subject of safeguards to prevent peaceful nuclear technology from leading to the proliferation of nuclear weapons.

The Soviet decision to participate (just 2 weeks before the conference opened) prompted a flurry of activity by the U.S. State Department to bring an American position on safeguards to the technical meeting scheduled to follow the Geneva conference. The American delegation to the safeguards meeting was led by Isadore Rabi and attempted to develop a U.S. position over the 5 days that were available prior to the agreed-upon meeting. Little prior thinking about the subject had occurred beyond the notion of emphasizing physical security of fissionable materials and detecting violations of rules created by the projected IAEA. It became apparent in the discussions among the Americans (in hotel room meetings at night) that the safeguards issue was complicated, difficult, and likely expensive. The American team settled on a proposal to assist material accounting with tagging fissionable material with a radioactive element, U-232, that would allow detection of the material in the plant. Material accounting would be accompanied by a system of physical security and inspection. The Soviets, led by Dmitri Skobeltsyn, were skeptical of the pro-

posal and pointed out some technical problems with the use of U-232 as a taggant that the United States had not taken into account. In addition, the U.S. team expressed a lack of confidence in the long-term viability of its own safeguards proposal.

Following the safeguards meeting, and in advance of a meeting to draft the IAEA statute, the U.S. Atomic Energy Commission (AEC) created a task force to produce ideas and studies for safeguards. It contracted with the Vitro Corporation to produce an engineering study of safeguards to allay the concerns expressed over the effectiveness of the American proposals. The Vitro study concluded that even with a 90 percent probability of detecting diversions of nuclear materials, it would be possible to divert enough plutonium for one bomb from a power reactor within a period of 5 years. This meant that safeguards would have to have a political and diplomatic component as well as a technological one.

The task force concluded that Atoms for Peace might contribute to proliferation, that is, atoms-for-peace could lead to atoms-for-war. However, the AEC was not prepared to slow down, let alone abandon, the Atoms of Peace program. Although the agency explicitly recognized that there was no diversion-proof safeguards system, the commission supported taking the proliferation risks of going ahead with the program. The result was inevitable. The United States provided research reactors and training to dozens of countries, and some of them used the assistance to advance their interest in making nuclear weapons. India, Pakistan, and Israel all received assistance under Atoms for Peace. Much attention in recent years has been paid to the Iranian nuclear program and the concern about whether Iran is moving toward a nuclear weapon ca-

pability. Most of the stories do not mention that Iran's nuclear interest began in the late-1950s with a research reactor provided by the United States under Atoms for Peace. The cavalier attitude on safeguards at the beginning of the nuclear age has been matched by the attitude toward nonproliferation failures in more recent years.

The failure to tie an effective safeguards system to earlier nuclear development was made manifest during negotiations on the extent of safeguards. For example, the question arose as to whether safeguards should be applied to source material. The United Kingdom (UK), Belgium, Canada, and Australia supported this, but France and India were opposed. The opposition prevailed, making inventory accounting of source materials a purely voluntary activity. Another issue was whether safeguards should apply to all nuclear states. India supported this, but the five permanent members of the Security Council (the P-5), wanted to exclude themselves from such a provision so they proposed that safeguards should attach only to those states that receive technical assistance from the IAEA, thereby leaving out the P-5.

Finally, the issue arose as to whether there could be multilateral or alternative bilateral safeguards in lieu of international safeguards under the IAEA. The United States, realizing that it would take another few years to establish an international system and not wanting to wait for such a system to be put into place before engaging in nuclear trade, supported the notion of bilateral or multilateral safeguards in nuclear transactions. Thus, when the European Atomic Energy Community (Euratom) was established, the United States supported Euratom's desire for its own safeguards system, which undermined the authority of the IAEA system at the very beginning.

But this was not the only problem making it difficult for safeguards to perform their stated function (deterring diversion via the risk of timely detection). Safeguards are still primarily focused on declared facilities. The additional protocol of the IAEA which allows, *inter alia*, for environmental monitoring, is meant to take care of this gap in coverage, but only about 60 percent of NPT signatories have ratified it. Special inspections ostensibly can be used to investigate suspicious activity at a site, but inspectors require the cooperation of the state and, the threat of sanctions notwithstanding, are unlikely to be given access if inspections would reveal a violation.

Another problem in practice concerns the unrealistic timeliness goal of the safeguards system. Material balances are done on a yearly basis, while diversions can occur at any time. This can be overcome by increasing the number of inventory takings, but that increases the cost and is resisted by plant operators.

Finally, the official definition of a significant quantity (SQ) of highly enriched uranium (HEU) or plutonium (Pu) (that is, the amount of material needed to produce a nuclear explosion) is obsolete. For HEU, one SQ is defined as 25 kilograms, and for Pu, one SQ is 8 kilograms. Weapon states have produced working weapons with significantly smaller amounts of materials. Moreover, even considering the official numbers, in bulk handling plants processing large amounts of such materials, the minimum detectable diversion over a period in which a bomb can be constructed will exceed one SQ by far.

In response to all these problems with safeguards, technical and institutional advances to prevent proliferation have been incorporated into the nonproliferation regime. Among these are near real time

accounting, the physical security convention, better intelligence and surveillance, the additional protocol, export controls, and increased use of the Security Council to impose sanctions on violators. Ultimately, of course, the system depends on the willingness of countries to carry out enforcement actions to deal with safeguards violations or other violations of international norms, and this is central to the problem discussed in Chapter 4.

Although Gilinsky mentions a number of cases where the United States failed to act appropriately upon knowledge of violations, his main focus is on the Nuclear Materials and Equipment Corporation (NUMEC) affair in which Israel apparently and illegally received hundreds of kilograms of HEU from a U.S. Navy contractor in Apollo, PA. This was an egregious example of misfeasance by the U.S. Government. But equally bad is the example of Pakistan having obtained the means for making nuclear weapons that Gilinsky ascribes to a U.S. policy of "benign neglect" because of Pakistan's role in the Cold War. Neglect it certainly was, but there was nothing benign about it. During the most critical period of Pakistan's drive to obtain nuclear weapons in the 1980s, the executive branch of the U.S. Government got Congress to amend U.S. nonproliferation laws to allow economic and military assistance to Pakistan and then repeatedly ignored violations of the laws for the same purpose.

Here is a list of the actions or nonactions taken by the U.S. Government that gave Pakistan the confidence that it had little to fear from U.S. nonproliferation laws as long as the Cold War was still the primary focus of U.S. foreign policy and the Soviet invasion of Afghanistan was still ongoing:

1. In 1981, a new law was enacted, giving a 6-year waiver to Pakistan of the provisions of the Symington Amendment to the Foreign Assistance Act. Pakistan had previously been denied economic and military assistance under the amendment by importing unsafeguarded nuclear enrichment technology and equipment. The waiver allowed Pakistan to obtain a $3.2 billion aid package despite the continuation of its nuclear weapon acquisition activities. The waiver was extended a number of times until the Soviets began to leave Afghanistan in 1989.

2. Agents for Pakistan repeatedly attempted to illegally smuggle materials and components useful for the manufacture of nuclear weapons out of the United States, and were either not prosecuted or were allowed to leave the country without heavy penalty.

a. In 1981, while an aid package for Pakistan was being considered by Congress, a Pakistani agent attempted to smuggle 5,000 pounds of zirconium for nuclear fuel rods out of the United States. The attempt was foiled by U.S. customs agents but had no effect on congressional passage of the aid.

b. A Pakistani agent named Nazir Ahmed Vaid was arrested in 1984 for illegally attempting to export krytrons, which are used for nuclear triggers. Although the known intended recipient was the Pakistan Atomic Energy Commission, the indictment was rewritten to exclude any mention of the nuclear use of krytrons. Vaid was permitted to plea bargain to a reduced offense, thus avoiding a jury trial, and a gag order on the case was issued by the judge. Vaid was found guilty of one count of an export violation and was quietly deported 3 weeks later. Although the case had no effect on U.S. aid to Pakistan, it did cause Con-

gress to pass the 1985 Solarz Amendment to the Foreign Assistance Act, which prohibited economic and military assistance to any country that illegally exports or attempts to export U.S. items that would contribute significantly to that country's ability to make a nuclear explosive device.

c. In 1987, a Canadian citizen of Pakistani descent named Arshed Pervez was arrested for illegally attempting to buy and export a quantity of beryllium (used as a reflector in the core of nuclear weapons) along with 25 tons of maraging steel (a special steel used for constructing high speed centrifuges) from an American manufacturer. He was convicted of the beryllium charge and of lying to investigators but escaped conviction on the remaining charges on the grounds of entrapment even though American intelligence officials found evidence that he was working for a retired Pakistani brigadier general and that the final customer was the Pakistan nuclear program. This was a violation of the Solarz Amendment, but no sanction ensued.

3. In 1985, the Pressler Amendment was signed into law, which made military assistance to Pakistan contingent on an annual certification by the president that Pakistan did not possess a nuclear explosive device. Pakistan had the bomb by 1987, but the administrations of U.S. Presidents Ronald Reagan and George H. W. Bush continued to make the determination that Pakistan did not possess a nuclear explosive device until 1990, when the last Soviet soldiers were leaving Afghanistan.

4. The sanctions visited on Pakistan following the reimposition of the Symington and Glenn Amendments, as well as the application of the Pressler Amendment, did not last long once the U.S. concern about the Soviets was replaced by the specter of Islamic terrorists after September 11, 2001. When the United States decided to wage war in Afghanistan and needed the help of the Pakistan Inter-Services Intelligence agency (ISI) to do so, the nonproliferation laws were again altered or replaced so that Pakistan could receive its desired arms shipments. The nuclear tests carried out by Pakistan (and India) in 1998 made no difference, as the United States continued to change its laws for Pakistan's (and India's) benefit. Even the rise of the infamous A .Q. Khan network that spread nuclear bomb material manufacturing technology to many countries, including Iran and North Korea, made no difference.

The characterization of the U.S. attitude toward the Pakistani nuclear program during these years is more accurately called "supine indulgence" rather than "benign neglect." It has provided the two current *bêtes noire* of the United States in nuclear matters, Iran and North Korea, with the ability to claim that U.S. oppositional rhetoric to their programs on the grounds of principle constitutes hypocrisy. That is not to say that they have no fear of U.S. military action. Quite the contrary; but all parties understand that if it comes to that, it will not be primarily in defense of nonproliferation norms, although that is how it may be advertised. Rather it will be in support of the maintenance of regional U.S. power and influence against the survival and regional power ambitions of Iran in the Middle East and North Korea in East Asia.

It is frequently said, usually by people with a particular fondness for realpolitik, or who have a foreign policy axe to grind on behalf of a client, country, or industry that is behaving badly on nuclear issues, that U.S. interests in nonproliferation cannot be allowed to supersede broader U.S. national interests (defined by them as helping said client, country, or industry). Such philosophy relegates nonproliferation policy to a contingency to be exercised when convenient to do so. It is another version of the old saw that says nations do not have permanent friends or enemies, only permanent interests, which in this case excludes nonproliferation except in special circumstances. And there is no question, when examining the U.S. record (not just the rhetoric of its leaders), that the United States has yet to see nonproliferation as a permanent interest transcending alliances and ideology. Regardless of whether this as a good thing or a bad thing, it cannot be expected that other nations will be persuaded to view the issue differently, and that leads to the problems with the nonproliferation regime, including the one encapsulated in the title of Chapter 4.

## ENDNOTES - CHAPTER 5

1. Victor Gilinsky, "Sometimes Major Violations of Nuclear Security Get Ignored," Chapter 4 of this Book, p. 51.

2. Winston Churchill, *The Second World War, Vol. I, The Gathering Storm*, London, UK: Penguin, 1985, p. 119.

# PART III

# CHAPTER 6

# CAN THE IAEA SAFEGUARD FUEL-CYCLE FACILITIES? THE HISTORICAL RECORD

**Alan J. Kuperman**
**David Sokolow**
**Edwin S. Lyman**

## INTRODUCTION

The peaceful use of nuclear power is premised on an international ability to prevent bomb-grade nuclear materials from going missing from civilian fuel-cycle facilities. This depends crucially on "safeguards" administered by the International Atomic Energy Agency (IAEA), which are supposed to detect any clandestine removal of a bomb's worth of fissile material (or more) in time to prevent it from being manufactured into one or more nuclear weapons. Unfortunately, more than 4 decades after the creation of IAEA safeguards, considerable doubt remains as to whether the agency can attain this goal even at the relatively small number of existing fuel-cycle facilities, let alone at the many more such facilities envisioned as nuclear power expands globally.

Accordingly, this chapter assesses the current and anticipated efficacy of IAEA safeguards at civilian fuel-cycle facilities (also known as "bulk handling facilities") and then formulates policy recommendations. The chapter starts by detailing the empirical record of safeguards shortfalls at such facilities. Second, it explains the two major risks of clandestine removal of fissile material from fuel-cycle facilities: diversion by

states, or theft by sub-state insiders. Third, it details the scope of such facilities worldwide. Fourth, the chapter discusses the technical and political obstacles to achieving safeguards objectives, and various proposals to overcome them. Finally, the chapter concludes with policy recommendations based on the current and projected capabilities of IAEA safeguards.[1]

## EMPIRICAL RECORD

Nuclear fuel-cycle facilities around the world, in states with and without nuclear weapons, have suffered accounting discrepancies entailing many bombs' worth of fissile material. This section first explores the record at such facilities in two nuclear-weapons states: the United Kingdom (UK) and France. Second, it illustrates the inadequacy of accountancy at such facilities under IAEA safeguards in two countries with varying levels of cooperation with the agency: Japan and Iran.

### United Kingdom.

British Nuclear Fuels Limited's (BNFL) Sellafield site in northwest England includes a mixed-oxide (MOX) fuel facility, which operated from 2001 to 2011, as well as the Thermal Oxide Reprocessing Plant (THORP) that continues to operate. In 2005, an audit of the nuclear materials at the MOX facility revealed that the "material unaccounted for" (MUF) was 29.6 kilograms (kg) of plutonium, or roughly 3.5 "significant quantities" (SQ) of this fissile material, enough for several nuclear weapons. BNFL insisted that the figure did not mean that any material had been removed without authorization from its plants. The company asserted that its techniques to account for

nuclear material followed internationally approved and recognized best practices. In particular, BNFL contended that the systems of statistical measurement and control at THORP were "the most advanced in the world."[2] However, on May 9, 2005, a BNFL inquiry revealed that a massive leak at THORP had gone undetected for 9 months. The leak occurred in a feed pipe to one of the two accountancy vessels, resulting in accumulation of 83.4 cubic meters of dissolver solution. This solution contained an estimated 19 metric tons of uranium and 190-kg of plutonium.[3] An accountancy tank is where the initial inventory of fissile material is measured for the purpose of establishing shipper-receiver differences (SRD). But the system failed to detect the increasing loss of material until 8 months after it began. To the credit of the plant's material accounting system, the first indications of the problem came not from any safety detectors (several of which were malfunctioning), but from the company's Safeguards Department, when it observed an anomalous SRD in March. Despite that, the leak was not uncovered until a month later.

In BNFL's review of the incident, the company commended the role of its Safeguards Department in detecting the leak, although acknowledging that the Nuclear Materials Accountancy system had not provided timely warning of lost material. The system "is intended to provide overall accountancy balances," and "is not designed to (nor is it intended that it should) be responsive to track material on a more real time basis." Later, BNFL recommended the introduction of "a nuclear tracking regime . . . with the objective of promptly detecting primary containment failure or misdirection of material."[4] This statement appears puzzling since BNFL had previously made claims,

with the full support of the European Atomic Energy Community (Euratom), proclaiming the existence of near-real-time accountancy (NRTA) at THORP. For example, in a paper delivered at an IAEA safeguards symposium in 2001, a joint BNFL-Euratom team stated that: "Near Real Time Materials Accountancy (NRTMA) is fully operational in THORP, providing regular assurance of high quality material control."[5] In retrospect, this claim appears to have been exaggerated, at the least.

At the time of the incident, the plant was under Euratom safeguards. This institution has identical timeliness criteria as the IAEA for uncovering diversions of nuclear material (e.g., the detection of one SQ of direct-use fissile material within 1 month). However, Euratom failed to detect the MUF despite having access to the operators' accountancy records, as well as supposedly having access to process data, upon which it performed its own statistical tests.[6] Neither the plant operators nor the Euratom inspectors successfully detected the leak or sounded an alarm for 8 months—many times longer than the timely warning requirement. This incident suggests that even state-of-the-art safeguards cannot come close to satisfying the IAEA's explicit standards for detecting missing fissile material before it could be fabricated into a weapon.

**France.**

Along similar lines to the BNFL incident, the now closed MOX fuel facility in Cadarache, France, which operated under Euratom safeguards, encountered MUF situations twice during the last decade. This facility was operated from 1961 to 2004 by Cogema and then by Areva, which acquired Cogema. In

2002, the Euratom Safeguards Agency reported that "the annual verification of the physical inventory at Cogema-Cadarache plant in France found an unacceptable amount of material unaccounted for (MUF) on the plutonium materials [SIC]."[7] The problem was later attributed to the differences between measurement techniques by inspectors and operators, and to poor definitions of materials in historical accounting records. (If the latter were the issue, it is unclear why the MUF problem would not have arisen until 2002.) In September 2004, it was reported that Euratom finally had responded to Cogema's explanation of the 2002 MUF finding.[8] Thus, it took at least 2 years to resolve the discrepancy. Despite this explanation, the problems at the facility persisted.

In October 2009, the French Nuclear Safety Authority ordered the halt of decommissioning operations at the facility. When the facility had closed in 2004, its former operator, Areva, estimated that there would be a MUF of approximately 8-kg of plutonium due to holdup in the plant's gloveboxes—which are shielded hot cells along the process line in which technicians can remotely manipulate the nuclear material. However, 2 weeks into the cleanup of the facility, the French Atomic Energy Commission announced that it had already collected 22-kg and projected that the total might rise to 39-kg of MUF.[9] While the plutonium holdup might have accumulated in the gloveboxes over a long period of time, Areva's underestimation of the amount by almost five SQs suggests that the plant's accounting system failed and that the Euratom safeguards were insufficient to detect the potential diversion of several bombs' worth of fissile material. The repeated failure of safeguards in nuclear-weapons states to meet the IAEA detection standards, despite employing some

of the most advanced accounting technologies in the world, raises serious questions about whether IAEA safeguards can achieve their objectives.

**Japan.**

Japan has boasted that it cooperates fully with the IAEA and applies the world's most advanced safeguards. Despite that, three of its fuel-cycle facilities have suffered substantial accountancy failures. This record raises serious concerns about the ability of safeguards to detect the diversion of fissile materials in a timely manner in any country.

At the Plutonium Fuel Production Facility (PFPF), a MOX fuel plant at Tokai-mura, the problem of residual holdup led to a significant material accountancy failure. Soon after the plant started up in 1988, operators noticed the problem of plutonium becoming stuck in gloveboxes. In response, the plant operator, Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC), in conjunction with safeguards experts at the U.S. Los Alamos National Laboratory, designed a nondestructive assay (NDA) method to measure residual holdup *in situ*—that is, without dismantling the hot cells—known as the Glovebox Assay System (GBAS). However, the system's imprecision contributed to an overall measurement uncertainty of about 15 percent.

By 1994, the plant's MUF had grown to about 69-kg of plutonium. Because of the measurement uncertainty associated with the GBAS, even if the entire MUF were residual holdup, the IAEA could not exclude the possibility—with a confidence level of 95 percent, based on NDA measurements alone—that at least one SQ had been diverted. Consequently, the IAEA want-

ed PNC to cut open the plant's gloveboxes, remove the holdup directly, and measure it with destructive assay methods. PNC balked at this request, and the dispute remained unresolved until the Nuclear Control Institute—a Washington-based, nonproliferation advocacy group—publicly disclosed the existence of the discrepancy in 1994. After that disclosure, PNC agreed to shut down the plant, recover the holdup, install new equipment to reduce further holdup accumulation, and implement improved NDA systems to measure more accurately any future residual holdup. After an expenditure of $100 million to remove and clean out old gloveboxes and install new ones, PNC announced in November 1996 that it had reduced the MUF to less than 10-kg (but not less than one SQ). This partial resolution of the MUF issue took more than 2 years from the time the situation became public, which contrasts starkly with the IAEA's timely warning standard of 1 month for such fissile material that can be used directly to make a nuclear weapon.

Another long-unresolved MUF issue at Tokai was associated with the accumulation of plutonium-laden fuel scrap resulting from decades of MOX research and production activities at the site.[10] Press reports in the mid-1990s indicated that the scrap inventory at Tokai contained between 100- and 150-kg of plutonium.[11] However, much of this scrap was in an impure form that could not be accurately measured via NDA methods. An NDA instrument known as the Plutonium Scrap Multiplicity Counter (PSMC), developed by Los Alamos, was relatively effective for measuring pure scrap plutonium but much less so if the material was contaminated with moisture or light elements that could generate neutrons through (α,n) reactions. For heavily contaminated scrap, the measurement im-

precision ranged from 10 to 50 percent, well above the 4 percent uncertainty cited by the IAEA as the international standard for scrap measurements.[12] Even with the PSMC's best case of 10-percent average imprecision, the uncertainty associated with measuring a scrap inventory containing 150-kg of plutonium would be greater than one SQ. Indeed, more than six SQs would have to be diverted to yield a 95 percent chance of detecting a diversion. Accordingly, the IAEA wanted the plant operator, PNC, to chemically purify the scrap and then use destructive assay to measure the plutonium more precisely. In 1998, the IAEA announced a formal agreement under which PNC would embark on a 5-year program "aimed at reducing the inventory of heterogeneous scrap material," which would be "gradually homogenized to allow enhanced verification, including destructive analysis."[13] No further information appears to be available on the status of this program, except for a brief mention in the IAEA 2000 Safeguards Statement of a containment and surveillance approach for the receipt and storage of MOX scrap at the "Solution Critical Facility" in Japan.[14]

The older reprocessing plant at Tokai also has suffered substantial material accountancy failures due to measurement and estimation errors, since it began operating in 1977. In January 2003, Japan admitted that the cumulative shipper-receiver difference—that is, the amount of plutonium that was estimated to have been shipped to the reprocessing plant in spent fuel minus the amount of separated plutonium that had actually been measured—was 206-kg, or about 25 SQs. This was nearly 3 percent of the total plutonium estimated to have been processed in the plant over its lifetime. A few months later, Japan revised its figures, claiming that the actual discrepancy was only 59-kg,

because the remainder was either bound in the hulls of the spent fuel's cladding (12-kg), had been discarded with high-level liquid waste (106-kg), or had decayed into americium-241 (29-kg). However, it was unclear how figures as precise as these were derived, given the uncertainties inherent in measuring the plutonium in cladding hulls and in high-level waste, and in assessing the isotopic content of the spent fuel prior to reprocessing.

Japan's newest fuel-cycle facility is the larger, Rokkasho-mura Reprocessing Plant, which is now scheduled to commence commercial operations in 2016. Starting in the 1990s during design and construction, there was a massive multinational effort to develop and implement a state-of-the-art safeguards system at Rokkasho. Unfortunately, issues of cost and convenience played a major role in development of the safeguards approach and resulted in many questionable compromises. For instance, instead of having its own, independent, on-site analytical laboratory, the IAEA must share a laboratory with the facility operator, which raises the potential for tampering.

The IAEA itself admits that, after 15 years of designing the safeguards approach, the detection goals still cannot be met at the facility. In 2006, Shirley Johnson, the former head of the Rokkasho safeguards project in the IAEA's Department of Safeguards, acknowledged that even if the overall measurement uncertainty were between 0.7 and 0.8 percent at Rokkasho, the system could not come close to the detection goal of one SQ.[15] In a 2009 report for the International Panel on Fissile Materials (IPFM), Johnson reiterated the continuing problems in reducing measurement uncertainty, and called for complementary measures to address the concern:

> For a large facility like the Rokkasho Reprocessing Plant, which has an annual throughput of 800 tons of spent fuel containing about 1 percent plutonium (about 8,000-kg), a 1-percent uncertainty translates into an overall measurement uncertainty of 80 kilograms plutonium—10 significant quantities. For this reason, the IAEA requires added assurance by additional measures. Many of these could be carried out during short-notice random inspections.[16]

Unfortunately, such complementary measures have not yet been implemented. Nor have NRTA technologies solved the problem. Recent results from the performance of NDA solution monitoring systems at Rokkasho indicate that they also have high measurement uncertainty. For instance, it was reported that the Plutonium Inventory and Management System (PIMS), which is designed to perform assays on relatively pure plutonium and uranium mixtures, has a total measurement uncertainty of 6 percent (+/-).[17]

Although Japan sometimes blocks intrusive measures, claiming proprietary concerns, the IAEA has never accused the country of doing so out of an intention to divert fissile material. Indeed, it is despite Japan's apparent good-faith efforts to cooperate with the IAEA that its state-of-the-art safeguards have proved inadequate. As a result, the IAEA does not have high confidence that it could give timely warning of a potential diversion of enough fissile material for one or more nuclear weapons.

The shortcomings of safeguards are still greater in countries that withhold full cooperation from the IAEA and may have proliferation aspirations, such as Iran. As noted by the team that developed the safeguards approach for Rokkasho, "The most important

factor leading to the success" of a safeguards system is "the open and full cooperation between all parties—the IAEA, the State, and the operator."[18] Thus, even potential future enhancements of safeguards would likely fall short if there were an uncooperative or adversarial relationship between these parties. This is a crucial consideration as the IAEA and the world consider the expansion of nuclear power and fuel-cycle facilities to states with uncertain commitments to nuclear nonproliferation.

**Iran.**

Since 2003, the IAEA and international community have become increasingly concerned that Iran may use its enrichment technologies to produce highly enriched uranium for a nuclear weapon. To date, Iran generally has enriched no higher than to 20 percent at its three declared enrichment facilities (except for one small batch that inexplicably was enriched to around 27 percent),[19] and mostly to only about 4 percent. Ostensibly, the 20-percent enrichment is for research-reactor fuel, and the 4-percent enrichment is for power-reactor fuel, although none of this uranium has yet actually been used as fuel.

Several experts have analyzed how quickly Iran could achieve a "breakout" by enriching sufficient highly enriched uranium (HEU) for a nuclear weapon. In October 2012, the Institute for Science and International Security assessed "that Iran would require at least 2-4 months to produce one SQ of WGU [weapons-grade uranium] at the Natanz Fuel Enrichment Plant," the largest of its three such facilities, if it started from its then existing stocks of low-enriched uranium. The report added that "the quickest estimates are 2

to 2.3 months."[20] Similarly, a Nonproliferation Policy Education Center (NPEC) report, published a month earlier, examined the breakout potential if Iran used all three of its enrichment facilities and concluded that "The total time required is 73 days, which is about 10 weeks or a little less than 2 1/2 months."[21]

At the moment, IAEA inspections should be able to detect such an attempted breakout at a declared Iranian facility because "currently, inspections occur on average about once every 2 weeks, and some of them are unannounced."[22] But if Iran expands the number of its centrifuges and attempts to implement next-generation centrifuges, the required time for a breakout would shrink substantially. For example, according to the NPEC report, if Iran expanded its number of centrifuges by 12 times—without any improvement in technology and starting only from its stock of 4 percent low enriched uranium (LEU) rather than its 20 percent enriched stock—"these enrichment facilities could produce enough HEU for a nuclear weapon in just 2 weeks."[23] At that point, the IAEA's current schedule of safeguards inspections could not guarantee timely warning against a diversion of sufficient HEU for a nuclear weapon, even if Iran used only its declared enrichment facilities. An additional danger is that Iran could pursue a breakout at a clandestine enrichment facility, which current IAEA safeguards might not detect. As the IAEA conceded in August 2012:

> While the Agency continues to verify the non-diversion of declared nuclear material at the nuclear facilities and LOFs [locations outside facilities] declared by Iran under its Safeguards Agreement, as Iran is not providing the necessary cooperation, including by not implementing its Additional Protocol, the Agency is unable to provide credible assurance about the ab-

sence of undeclared nuclear material and activities in Iran, and therefore to conclude that all nuclear material in Iran is in peaceful activities.[24]

Suspected diversion from Iranian nuclear facilities is not merely hypothetical. The IAEA has reported accounting discrepancies at a separate Iranian nuclear facility, the Jabr Ibn Hayan Multipurpose Laboratories (JHL).[25] In 2011, the IAEA conducted a physical inventory verification at JHL "to verify, *inter alia*, nuclear material, in the form of natural uranium metal and process waste, related to conversion experiments carried out by Iran between 1995 and 2002."[26] This inspection revealed a discrepancy of 19.8-kg between the amounts of nuclear material declared by the operator and measured by the agency. Subsequently, in August 2012, after additional analysis and evaluation of clarifications provided by Iran, the agency reported that it had been able to reduce the discrepancy, and would continue to work with Iran to resolve the remainder.[27] As of the time this chapter was written in early-2013, however, the discrepancy had yet to be fully resolved, more than a year after it was originally discovered. This does not bode well, especially if Iran continues to expand its nuclear fuel-cycle facilities.

## TWO RISKS: DIVERSION AND THEFT

Civilian nuclear fuel-cycle facilities present two risks of clandestine removal of fissile material: diversion by states or theft by sub-state insiders for criminal or terrorist purposes. In both cases, the adequacy of safeguards is critical to providing the international community with timely warning to prevent the removed material from being fabricated into one or more

nuclear weapons. The fundamental goal of IAEA safeguards is to establish an accounting regime capable of reliably providing timely warning of the suspected clandestine removal of as little as one bomb's worth of fissile material, thereby helping to deter and prevent such an outcome. (This chapter does not cover the risks of overt attacks by sub-state actors on fuel-cycle facilities or shipments, or overt proliferation by states at formerly civilian facilities, which must be addressed by other national and international countermeasures.)

The potential for diversion and/or theft of bomb-usable nuclear material is present at three types of fuel-cycle facilities: (1) uranium enrichment, (2) reprocessing, and (3) MOX fuel fabrication. As explained later, these plants pose different vulnerabilities because of the different forms of fissile material that they routinely process.

Civilian enrichment facilities typically use centrifuges or other technologies to increase the percentage of the fissile U-235 isotope in uranium from its natural level of 0.7 percent to typically about 4 percent for use in the fuel elements of nuclear power plants. This output is known as "low enriched uranium," meaning less than 20 percent U-235, which is considered unsuitable for weapons. Civilian facilities typically do not produce "highly enriched uranium" (HEU)—meaning 20 percent or more U-235—which is considered necessary for weapons. Thus, the primary proliferation risks at civilian enrichment facilities are that the state could either (1) clandestinely produce and remove HEU, or (2) divert LEU to another facility not under safeguards for further enrichment.

Reprocessing facilities take the irradiated "spent" fuel that is removed from nuclear power plants and extract its plutonium (and uranium) for potential in-

corporation into fresh MOX fuel to be irradiated in nuclear power plants. The separated plutonium poses a major security risk because it can be fabricated directly into a nuclear weapon. Typically, such facilities contain plutonium in the form of oxides and other chemical mixtures that can either be used directly to make less efficient weapons or converted to metal for improved efficiency.

MOX fuel fabrication facilities take the plutonium oxide from reprocessing plants and mix it with uranium oxide to fabricate mixed-oxide fuel for nuclear power plants. MOX plants pose several security risks. Most obviously, they contain large amounts of separated plutonium oxide that can be used to make nuclear weapons. But even after the plutonium is combined with uranium to make bulk mixed-oxide material, and subsequently fabricated into MOX fuel, significant risk continues because the plutonium oxide can be separated out via chemical processes that are relatively straightforward. (This is much easier than reprocessing because the fuel is fresh and thus not highly radioactive.)

## SCOPE OF THE FACILITIES

The countries of main focus are those that have signed the Nuclear Nonproliferation Treaty (NPT) as non-nuclear weapon states, whose fuel-cycle facilities are subject to IAEA safeguards. But the chapter also discusses such facilities in nuclear-weapon states and in states that have not signed the NPT, as these plants may also offer some important lessons, especially if they are under stringent commercial safeguard regimes comparable to those of the IAEA.

Approximately 25 nuclear fuel-cycle facilities are operating in the world, with others proposed or temporarily closed, as detailed later. In 2012, there were 18 civilian enrichment plants operating, and three more were planned in 11 countries. Table 6-1 indicates their location, name, operational status, opening year, safeguards status, and capacity. Five commercial reprocessing facilities were operating, one was temporarily closed, and one was preparing to start up (see Table 6-2).

| Country | Facility Name | Operational Status | Opening Year | Safeguards | Capacity [tSWU/yr] |
|---|---|---|---|---|---|
| Argentina | Pilcaniyeu | Operating | 2010* | Yes | 20 – 3,000 |
| Brazil | Resende | Operating | 2005 | Yes | 115-120 |
| China | Shaanxi | Operating | 1997 | Yes | 1,000 |
| | Lanzhou II | Operating | 2005 | Offered | 500 |
| | Lanzhou (new) | Operating | 2005 | Yes | 500 |
| France | Georges Besse II | Operating | 2011 | Yes | 7,500–11,000 |
| Germany | Gronau | Operating | 1985 | Yes | 2,200–4,500 |
| Iran | Natanz | Operating | 2004 | Yes | 120 |
| | Qom | Operating | 2012 | Yes | 5 |
| Japan | Rokkasho | Operating | 1992 | Yes | 1,500 |
| Netherlands | Alemo | Operating | 1973 | Yes | 5,000 – 6,000 |
| Russia | Angarsk | Operating | 1954 | Offered | 2,200–5,000 |
| | Novouralsk | Operating | 1945 | No | 13,300 |
| | Zelenogorsk | Operating | 2009 | No | 7,900 |
| | Seversk | Operating | 1950 | No | 3,800 |
| United Kingdom | Capenhurst | Operating | 1972 | Yes | 5,000 |
| United States | Paducah, KY | Shutdown proposed | 1954 | Offered | 11,300 |
| | Piketon, Ohio | Planned | 2013? | Offered | 3,800 |
| | Eunice, NM | Operating | 2010 | Offered | 5,900 |
| | Areva Eagle Rock, Idaho | Planned | Postponed | Offered | 3,300–6,600 |
| | Global Laser Enrichment, Wilmington, NC | Planned | 2013 | ? | 3,500–6,000 |

Sources: Nuclear Fuel Cycle Information System, Vienna, Austria: IAEA, available from *infcis.iaea.org/NFCIS/NFCISMain.asp?Order=1&RPage=1&Page=1&RightP=List;* and Global Fissile Materials Report 2011, Princeton, NJ: International Panel on Fissile Materials, p. 32.

**Table 6-1. Civilian Enrichment Facilities.**

| Country | Facility Name | Operational Status | Opening | Safeguards | Capacity (tHM/yr) |
|---|---|---|---|---|---|
| China | Lanzhou Pilot Plant | Operating | 2001 | No | 50–100 |
| France | Areva La Hague UP2 | Operating | 1996 | Yes | 1,000 |
| | Areva La Hague UP3 | Operating | 1990 | Yes | 1,000 |
| Japan | Rokkasho | Starting Up | 2007 | Yes | 800 |
| | Tokai | Temporarily Shut Down | 1977 | Yes | 200 |
| United Kingdom | B205 | To be closed after cleanup | 1964 | Yes | 1,500 |
| | THORP | Operating | 1994 | Yes | 1,200 |

Sources: Nuclear Fuel Cycle Information System, Vienna, Austria: IAEA, available from *infcis.iaea.org/NFCIS/NFCISMain.asp?Order=1&RPage=1&Page=1&RightP=List;* and Global Fissile Materials Report 2011, Princeton, NJ: International Panel on Fissile Materials, p. 33.

**Table 6-2. Civilian Reprocessing Plants.**

As for MOX fabrication facilities, in the wake of the UK's 2011 announcement that its plant would close, only three commercial facilities—one each in France, Japan, and Russia—are currently in operation. Three more are planned to open during the next 4 years in Japan, Russia, and the United States (see Table 6-3). Japan Nuclear Fuel Ltd. had originally planned to open the Rokkasho-mura MOX plant in 2015, but the 2011 Fukushima nuclear disaster delayed construction on the facility by a year.[28] In Russia, the Mining & Chemical Combine plans to open a MOX facility at Zheleznogorsk in 2014. The U.S. MOX fuel facility at Savannah River will use plutonium from disassembled nuclear warheads and is scheduled to start operations in 2016 and begin producing commercial fuel in 2018.[29]

| Country | Facility Name | Operational Status | Opening | Safeguards | Capacity (tHM/yr) |
|---|---|---|---|---|---|
| France | MELOX-Marcoule | Operating | 1995 | Yes (Euratom) | 195 |
| Japan | Tokai | Operating | 2007 | Yes | 10 |
| | Rokkasho | Planned | 2016 | Yes | 130 |
| Russia | Mayak - Paket | Operating | 1980 | No | 5 |
| | Zheleznogorsk | Planned | 2014 | | 60 |
| United States | Savannah River | Planned | 2018 | | 100 |

Sources: *Nuclear Fuel Cycle Information System*, Vienna, Austria: IAEA, available from *infcis.iaea.org/NFCIS/NFCISMain.asp?Order=1&RPage=1&Page=1&RightP=List*; and "Mixed Oxide Fuel," London, UK: World Nuclear Association, available from *www.world-nuclear.org/info/inf29.html*.

**Table 6-3. Civilian MOX Fuel Facilities.**

## TECHNICAL AND POLITICAL CHALLENGES

The nonproliferation community has been aware for decades of the technical and political challenges facing safeguards. In 1990, Dr. Marvin Miller of the Massachusetts Institute of Technology (MIT) published a seminal paper, "Are IAEA Safeguards on Bulk-Handling Facilities Effective?" highlighting these challenges. Despite some progress over the past 2 decades, many of the challenges that Dr. Miller highlighted in 1990 still persist.

IAEA safeguards for nuclear facilities were designed with the objective of detecting with timely warning the diversion of a significant quantity of fissile material. An SQ is the "approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded."[30] In other words, an SQ is the estimated minimum amount

of uranium or plutonium (or other exotic fissile material) that a state or nonstate actor would need to build a nuclear weapon.

Depending on the type and form of fissile material, the IAEA guidelines adjust the amount that qualifies as an SQ and the deadline for timely warning. For unirradiated, direct-use nuclear material, an SQ is defined as 8-kg of plutonium, or 25-kg of U-235 in HEU, and timely warning is defined as 1 month after an abrupt diversion (or 1 year after the start of a gradual diversion). In 1975, the Standing Advisory Group on Safeguards Implementation (SAGSI) was established as a group of external experts appointed by the IAEA Director General to provide feedback on safeguards standards, among other functions.

Material accountancy is how the IAEA aims to detect the diversion of nuclear material at civilian fuel-cycle facilities. This is analogous to an audit. Operators of nuclear facilities prepare a material balance for a specific period of time showing that all nuclear material can be accounted for. To prepare this balance, the operators add material inputs—and subtract removals—from the quantity indicated at the start of the accounting period, yielding an amount that should match the ending physical inventory. The IAEA performs an independent assessment on at least some of the data provided by the facility operator to verify that there has not been any deliberate falsification of data.[31]

Discrepancies between the operator's final physical inventory and the amount that its records indicate should be present are labeled MUF. Such discrepancies can arise from problems such as accumulation of residual holdup in the process lines, accumulation of scrap and waste materials in other material forms that

are hard to assay, inaccuracies in nuclear material estimation methods, operator incompetence, diversion, or theft. MUF is often caused by residual holdup, resulting from the adhesion of fissile-material powders on process equipment, including in cracks, corners, and pores. Because of the layout and design of fuel-cycle facilities, these MUFs can grow over time and may only be resolved by dismantlement and careful clean-out. Unless and until the source of the MUF can be identified, it is impossible to rule out the possibility of diversion or theft, which poses a dilemma. If inspectors declare a possible theft or diversion, it may well be a false alarm. But if they refrain from doing so for fear of a false alarm, it may be impossible to satisfy the IAEA's timely warning criteria.

False alarms thus pose a serious quandary for safeguards. The SAGSI guidelines recommend that safeguards be stringent enough to provide at least a 90 to 95 percent probability of detecting a diversion with a false alarm rate of less than 5 percent. Some critics have argued that this detection probability is too low, because it permits a 5 to 10 percent chance of a diversion going unnoticed. But merely raising the probability of detection, if all else remains equal, will also increase the false-alarm rate. Such increases in false alarms are a nuisance and impose costs by interrupting facility operations. Moreover, based on past experience, high false-alarm rates may spur operators to ignore alarms or even switch off the detection systems, thereby perversely reducing the probability of detection.

Unfortunately, real-world detection probabilities at fuel-cycle facilities are even lower than recommended by SAGSI. The IAEA has acknowledged that it cannot meet the goal of a 90 to 95 percent probability of

detecting the diversion of an SQ. So, instead, the IAEA adopted a relaxed standard known as the "accountancy verification goal" (AVG), which was "based on a realistic assessment of what then-current measurement techniques could actually detect," according to a U.S. congressional report.[32] In other words, rather than designing safeguards to meet the desired detection standard, the IAEA instead has lowered that detection standard, so it could be satisfied by current safeguards.

The AVG is based on a measure called E, defined as the "minimum loss of nuclear material which can be expected to be detected by material accountancy," which varies depending on a facility's input, among other factors. The formula for E was derived from the joint requirements of a 95 percent confidence of detecting a diversion and a 5 percent false-alarm rate. For a large reprocessing facility, based on an input uncertainty of 1 percent (+/-) and an annual input of 800 metric tons of heavy metal (spent fuel), the value for E would be 246-kg of plutonium, or more than 30 SQs. In other words, there would be less than a 95 percent probability of detecting a diversion of 30 bombs' worth of plutonium. Any smaller diversion would have an even lower probability of detection. In particular, the probability of detecting the diversion of a single SQ—enough for a nuclear weapon—would be minimal.

Despite technological advances in monitoring and accounting systems since 1990, large MUFs have occurred repeatedly at facilities with IAEA-quality safeguards, as detailed earlier. These failures have arisen both in non-nuclear weapons states, subject to IAEA safeguards, and in nuclear weapons states subject to analogous domestic regulations.

## PROPOSED IMPROVEMENTS

For at least 3 decades, nonproliferation experts have outlined theoretical proposals for improving safeguards. But practical obstacles, including proprietary concerns, have prevented their thorough implementation. In his 1990 paper, Miller focused on three areas:

1. **Reducing measurement uncertainty in the chemical process area**. Unfortunately, no progress is apparent in this realm. As of 2001, the IAEA's "expected measurement uncertainty" associated with closing a material balance at a reprocessing plant remains at 1 percent.[33] Miller reported the same value in 1990.

2. **Near-real-time accountancy on a weekly basis to improve the detection of protracted, low-level diversion**. In NRTA, inventories are taken and material balances closed on a much more frequent basis than the conventional annual physical inventory. For instance, Miller showed that the threshold for detection of an abrupt diversion of one SQ of plutonium at a fuel-cycle facility could be accomplished by use of NRTA with physical inventories conducted on a weekly basis. However, given that the time to take a physical inventory of a large facility is approximately 1 week—including preparation time, cleanout of process of equipment, measurement of the inventory, and reconciliation of the anomalies—such a high frequency of physical inventories is impractical.[34] Therefore, NRTA must resort to nondestructive assay measurements of in-process materials where possible, and its effectiveness will depend in large part on the uncertainties associated with these measurements. A major question is whether NDA techniques have improved over the past 22 years to the extent that the benefits of NRTA can be fully realized.

3. **Reducing measurement error of plutonium in the waste stream, such as in cladding hulls and sludges**. Over the past decade, Los Alamos National Laboratory and other labs have explored ways to improve the capabilities of NDA instruments for waste measurements. The development of neutron multiplicity counters and high-efficiency epithermal neutron counters showed some promise in improving the precision of measuring plutonium in waste drums. However, these instruments do not perform well when measuring low-assay, contaminated, and heterogonous plutonium materials—as is typical in waste streams.

A holistic approach to reducing measurement uncertainties is known as safeguards by design (SBD). Under SBD, future civilian nuclear fuel-cycle facilities would be designed, constructed, and operated in a manner to incorporate the most advanced technology and systems to enforce IAEA safeguards. Proponents of SBD assert that this approach can:

> ensure the timely, efficient, and cost effective integration of international safeguards and other nonproliferation barriers with national material control and accountability, physical protection, and safety objectives into the overall design process for a nuclear facility.[35]

But the future viability and success of SBD depends upon developing better monitoring and accountancy equipment, reducing the costs associated with these new designs and technologies, and alleviating proprietary concerns.

While such technical solutions could in theory enhance IAEA safeguards, proprietary and sovereignty concerns have hindered their implementation. States and nuclear firms have been reluctant to allow the

IAEA access to the design, construction, and operation of their fuel-cycle facilities because they fear loss of intellectual property. For example, in 2004, Brazil initially prevented IAEA officials from inspecting equipment at the Resende enrichment facility, in order to protect proprietary information. When the IAEA inspectors arrived at the plant, they discovered that large portions of it were behind walls and coverings.[36] Later in 2004, Brazil and the IAEA did reach an agreement to allow the inspectors to visit the site.[37] However, this incident demonstrates that even countries that have abandoned their pursuit of nuclear weapons and are responsible, active members of the international community (such as Brazil) are reluctant to provide the IAEA with unrestricted access to commercial fuel-cycle facilities due to proprietary concerns.

Other countries, such as Iran, may be hesitant to comply with the IAEA so that they can maintain their weapons option. Such countries may fear that the IAEA would provide detailed information about their facilities to their enemies. Top Iranian officials express this fear. For example, then-Iranian President Mahmoud Ahmadinejad labeled the head of the IAEA a puppet of the United States, and he accused the IAEA of making "illegal requests" during its inspection efforts.[38] In September 2012, the head of Iran's Atomic Energy Organization, Feyerdoon Abbasi-Davan, claimed that "terrorists and saboteurs might have intruded the agency and might be making decisions covertly."[39] Despite nominally placing all of its nuclear facilities under a safeguards agreement, Iran continues to deny the IAEA unfettered access to all of its nuclear-related facilities.

Given the limitations of safeguards, the IAEA increasingly has relied during the last 2 decades on com-

plementary measures of containment and surveillance (C/S), especially seals and cameras. For example, reprocessing plants have begun to utilize seals on their tanks containing liquid plutonium nitrate, which is an interim form of the material during the plant's operation, in order to detect unauthorized withdrawals. Some reprocessing plants also have installed cameras to monitor the spent fuel pool and the transfer of spent fuel to the chop-leach cell to detect efforts to divert for clandestine reprocessing. Unfortunately, many parts of a reprocessing plant cannot be monitored with cameras or seals, because of the myriad pipes, valves, pumps, and tanks. Thus, although C/S measures are a useful complement to safeguards, they are no substitute for better accounting measures, such as NRTA.[40]

In 1997, due to concern about clandestine facilities, the IAEA introduced an additional protocol, which it aimed to negotiate with each state already subject to a comprehensive safeguards agreement. This would provide the IAEA "complementary access . . . to assure the absence of undeclared nuclear material and activities."[41] To induce states to sign the additional protocol and to save money, the IAEA also introduced the concept of integrated safeguards. Under this approach, the agency relaxes the inspection requirements at declared facilities, on grounds that its "state-level" approach can detect any nondeclared facilities where diverted material would need to be further processed for a nuclear weapon. The state-level approach depends on factors such as the state's own domestic accounting mechanisms and its willingness to accept remote monitoring and short-notice random inspections.[42] As the agency explains:

> when the IAEA has drawn a conclusion of the absence of undeclared nuclear material and activities in that State . . . [accountancy] measures may be applied at reduced levels at certain facilities, compared with the measures that would have been applied without this conclusion.[43]

SAGSI concluded in 2004 that such "Safeguards Criteria were basically sound,"[44] and in 2010, the IAEA reported that 47 states had implemented integrated safeguards.[45]

But serious questions have been raised about whether integrated safeguards are an adequate substitute for facility-level accounting. The approach depends on high confidence that the IAEA can detect all clandestine facilities in a country and that fissile material cannot be diverted to a second country for processing, both of which are questionable assumptions.[46] Some aspects of the state-level approach are laudable, including less predictable inspections and aiming to discover clandestine facilities,[47] but these should not come at the expense of watering down facility-level safeguards. Otherwise, integrated safeguards could wind up weakening, rather than strengthening, protections against misuse of fissile material.

Some nuclear security advocates, such as the IPFM, have proposed new ways to monitor fuel-cycle facilities in nuclear-weapons states—as would be required under a proposed Fissile Material Cut-Off Treaty (FMCT)—which might also be applicable at some facilities subject to IAEA safeguards.[48] To reduce costs of monitoring under an FMCT, an IPFM report in 2009 suggested that IAEA timeliness requirements could be relaxed in return for new verification and monitoring tools and methods, which it said would result in "only a relatively moderate increase in measurement

uncertainties."[49] For example, at operating commercial facilities, the report recommended short-notice random inspections rather than continuous inspector presence.[50]

While IAEA safeguards are an international audit mechanism, analogous domestic measures are generally known as state systems of accounting and control (SSACs), which help monitor nuclear materials in a country and may provide the framework for the application of safeguards under an agreement between the state and the IAEA. These agreements include, but are not limited to, protocols for measurement systems to determine quantities of nuclear material and procedures governing the taking of a physical inventory. The IAEA does not have formal authority to address subnational threats, such as theft by workers at a facility ("insiders"). But improving SSAC to help the IAEA detect diversions by the state can also provide the operator an enhanced capability to detect diversions by sub-state insiders.[51] Unfortunately, additional aspects of domestic security that are important in countering internal threats, such as access authorization programs, remain out of the IAEA's formal domain, even under the provisions of the 2005 amendment to the Convention on Physical Protection of Nuclear Material which, in any case, has not yet entered into force. This distinction between state and nonstate actors is artificial when their interests are intertwined, so it may hinder efforts to build comprehensive systems to effectively ensure that civil nuclear facilities do not become covert sources of fissile material for states or subnational groups.

Domestic authorities also are responsible for "physical protection," which seeks to detect and prevent loss of nuclear material in real time, in contrast to

accountancy that can only detect it after the fact. Many of the technological aspects of physical protection are known as material control and accounting (MC&A), which comprises aspects of safeguards, in addition to containment and surveillance. At fuel-cycle facilities, MC&A includes but is not limited to locks, fences, walls, gates, and badging systems. It also may incorporate interior and exterior sensors such as video cameras and motion detectors to prevent outsiders from breaking in or insiders from gaining access to sensitive areas and materials, and to improve response time to alarms. Such systems also may monitor pedestrian and vehicle exits to detect attempts to remove materials.[52] Beyond MC&A—which comprises these technological approaches to detection, deterrence, and prevention of nuclear theft—physical protection programs also include additional response and deterrence elements, including armed forces.

## CONCLUSION

Theoretical solutions to improve IAEA safeguards have been discussed for decades. However, proprietary, economic, and sovereignty concerns have limited the extent to which countries and private companies have implemented these theoretical solutions. Even in states that cooperate with the IAEA and apply sophisticated accounting mechanisms, such as Japan, safeguards at fuel-cycle facilities currently cannot come close to achieving their explicit goal of providing timely warning of a suspected diversion of one bomb's worth of fissile material. The prospects are even worse in states that resist cooperation and may wish to keep open their weapons option, such as Iran, and at facilities that employ first-generation safeguards.

If the prospect of an undetected diversion or theft of fissile material is unacceptable to the international community, then it is imprudent to permit the construction of additional nuclear fuel-cycle facilities, or expansion of existing ones, especially in states of proliferation concern, unless and until safeguards can be substantially upgraded to meet the international community's explicit detection goals. Considerable resources should be devoted to research and development of such improvements. But if past experience is any indicator, significant progress is unlikely to occur anytime soon. That stubborn reality should inform nuclear policy decisions. Most importantly, it suggests that the international community should postpone consideration of expanding the recycling of spent nuclear fuel, because that would require additional reprocessing and MOX fuel fabrication facilities that cannot now be safeguarded adequately against diversion or theft for nuclear weapons.

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# CHAPTER 7

# REVIEW OF "CAN THE IAEA SAFEGUARD FUEL-CYCLE FACILITIES? THE HISTORICAL RECORD"

**Ryan A. Snyder**

In Chapter 6, "Can the IAEA Safeguard Fuel-Cycle Facilities? The Historical Record," Alan Kuperman, David Sokolow, and Edwin Lyman provide a reminder of safeguarding challenges at fuel-cycle facilities by citing material accountancy failures at such facilities in England, France, Japan, and Iran. The known technical challenges of meeting the International Atomic Energy Agency (IAEA) safeguards objective are discussed, but many of the examples and much of the surrounding discussion reveal that limitations to safeguarding efforts are not merely technical. There are human factors that likely contributed to the material accountancy failures over months or years, as well as IAEA credibility considerations that probably delayed disclosures of material diversions. In addition, the technical challenge is greater than discussed, as nuclear weapons with sizeable yields can likely be manufactured with less material than was assumed.

Two examples of missing material that Kuperman, Sokolow, and Lyman cite are the 22 tons of uranium and 160 kilograms (kg) of plutonium found missing in 2005 at the Thermal Oxide Reprocessing Plant (THORP) in England, and the 206-kg of plutonium that was reported missing in 2003 at the Tokai reprocessing plant in Japan. It is tempting to claim that the IAEA simply lacks the capabilities to measure such diversions, but the amount of material missing in

both cases suggests that either the measurement errors are much higher than claimed in the 2001 IAEA Safeguards Glossary or that no measurement or inexcusably few measurements were made until other signals alerted inspectors or operators to large amounts of missing material. It should be mentioned here that even though the IAEA was not responsible for safeguarding the THORP, there is no reason to assume that the technical capabilities of those responsible at the Euratom Safeguards Agency should have differed markedly from those at the IAEA.

The 206-kg found missing at Tokai was about 3 percent of the total plutonium processed over the plant's lifetime since 1977. The expected error for such a measurement at a reprocessing facility is about 1 percent, according to the IAEA.[1] While the percent of total throughput of the uranium and plutonium found missing at the THORP is not listed, the size of the leaks were almost certainly higher than 3 percent of total plant throughput between the roughly 8 months from the start of the leak to its discovery.

It is necessary here to mention what the IAEA says must be measured to have the required confidence that a material diversion has occurred. Any scientific measurement must have some uncertainty, so there is always some chance that a quantity is actually higher or lower than the number measured. This amount higher or lower divided by the measured value is called the measurement error, and the IAEA expresses this as a percentage. The IAEA also wants to be about 90-95 percent confident that, in fact, a measured material diversion has occurred, and this translates into needing measurements to differ from the original amount by 3.3 multiplied by the measurement error to claim this level of confidence. This rule is derived from ba-

sic statistics to reflect the IAEA's stated 90-95 percent confidence standard.

Knowing this, 3.3 times the expected error of 1 percent is 3.3 percent, which translates into an amount that is a bit higher than the 206-kg missing at Tokai when considering the total plant throughput. It is tempting to think that 206-kg of plutonium missing from a reprocessing facility could go undetected if it is only 3 percent of the total; it would not signal the 90-95 percent confidence needed for the IAEA to claim a diversion. However, if measurements with uncertainties of 1 percent were taken on multiple occasions over the life of the plant and if material equal to 3 percent of the throughput was indeed missing, statistics indicates that diversions over 3.3 percent of the throughput would still occasionally be measured and signal the necessary confidence to claim a diversion. The Tokai example suggests that either the measurement errors were not accurate to 1 percent or that measurements were not taken frequently enough to discover that material was missing.

Another way of thinking about such an idea is to consider counting out 100 pennies to make one dollar. If the measurement error here is 1 percent, it is expected that the total number of pennies counted would be between 99 and 101 most of the time. Now if a child entered the room and took three of the pennies without your knowledge, recounting them after the child's theft would most often give counts between 96 and 98. A count of 96 reflects a diversion equal to 4 percent of 100 and would exceed the minimum 3.3 percent difference needed to be confident that there has been a diversion. The important fact is that measurements with 1 percent error would sometimes create the appearance that four of the pennies are missing when

only three have been stolen. This applies analogously to the missing 3 percent of plutonium from Tokai; frequent measurements would occasionally result in diversions appearing to exceed 3.3 percent. The statistics of 1 percent measurements demand such outcomes.

The accountancy failure at Tokai is explained by human errors and not measurement limitations. Either the IAEA does not know what the standard errors are in measuring equipment used around the world, or it is claiming greater precision than the instruments have; an additional possibility is that users of the equipment do not know how to use it. It is also possible that no or very few measurements were taken, which adds another element into safeguarding efforts. Perhaps inspectors with high confidence in the operators at a particular plant or inspectors safeguarding plants located in countries deemed unlikely to divert material for use in a nuclear weapon will be more likely to skip material accountancy measurements. When so much material is found missing in the examples Kuperman, Sokolow, and Lyman cite from Tokai and THORP, the questions raised go beyond the IAEA's technical capabilities.

Additional human factors need to be considered in discussions about the IAEA's credibility related to false alarms or claims of a diversion when, in fact, none has occurred. The IAEA aims to keep this below 5 percent, which statistical calculations show is the previously mentioned standard of at least 3.3 multiplied by the measurement error. This consideration can be understood in the following way: If 20 measurements are made that meet the IAEA's threshold for diversion, one of those measurements is statistically likely to be false.

It is important to be aware of the problems the IAEA might encounter upon falsely claiming that a diversion has occurred. The agency is only able to do its work if it receives cooperation from states and if it made a claim that turned out to be false, cooperation in implementing safeguards might disappear. A state could say the IAEA was pressured by the United States so it could claim it has nuclear weapons ambitions and is interested in rallying international opinion for economic sanctions or military action against it. Future collaborative efforts between states and the IAEA could be in jeopardy, and the loss in trust from such an event could be a major setback.

Even though the chance of false alarms is a quantitatively expressed measurement, the political factors in bringing a claim of material diversion are highly relevant and add a challenging layer to safeguarding efforts. Any measure of material diversion with the required confidence will likely be repeatedly examined before a claim is brought against a state; the understandable risks of being wrong would likely demand it. This process will take time and, in the real event that material has been diverted, provide a state with additional time to build a nuclear weapon. A state could also say that the IAEA is mistaken or that it needs to check its own records to resolve the accounting discrepancy. This could delay any punitive action and buy yet more time.

Such factors could also lead states to conclude that diversions into nuclear weapons should be attempted with well-prepared excuses in preparation for the IAEA raising alarms. A state might calculate that it could divert material only to wait and see if the IAEA detects it. If the IAEA sounds an alarm, a state could attempt to creatively smooth over the dis-

crepancy and resolve it without fear of consequence. If the IAEA misses the diversion, then a state could proceed through the remaining clandestine steps to a bomb with greater confidence. That states considering the manufacturing of nuclear weapons will almost certainly give more thought into how to build them without detection than those trying to stop them raises the possibility that the IAEA is never likely to detect a material diversion it could confidently say was made for inclusion in a nuclear weapon. At least it seems unlikely, given the IAEA's constraints.

It is not unreasonable to ask whether the human factors in safeguarding efforts will always remain considerable limitations, no matter what improvements are made in measurement precision. The upgrades that Kuperman, Sokolow, and Lyman propose for safeguards would indeed be improvements, but they are all aimed at improving measurement error. Although vitally important, one must wonder whether any claimed improvements are indeed real and whether, if real, they would significantly improve efforts at meeting the IAEA's safeguards objective, which is:

> the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection.[2]

Might timely detection always be impossible when considering a state determined to build a nuclear weapon as quickly as possible upon diversion from a fuel-cycle facility? Improved measurement accuracy might provide greater confidence that, indeed,

some material is missing, but what are the limitations of such improvements? How much increased confidence is possible as a result? Should the human factors already discussed weigh more heavily—or perhaps dominantly—in considerations of safeguarding limitations?

The one quantitative definition that Kuperman, Sokolow, and Lyman did not discuss in enough detail was the definition of a significant quantity (SQ). The IAEA defines a significant quantity as "the approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded."[3] Kuperman, Sokolow, and Lyman use the IAEA's definition of 8-kg for a significant quantity of plutonium-239 (Pu-239), but this amount has been challenged as too large, given the information now publicly available about nuclear weapons design. This is an important oversight, as the effectiveness of a safeguards system depends on whether a diverted SQ can be detected, and the need to detect smaller quantities would place increased demands on safeguarding efforts. Most importantly, however, the IAEA's definitions in this regard are extraordinarily irresponsible if sizeable nuclear weapons can be built with smaller amounts of material than what the IAEA has defined as its concern. The question of whether it is possible to detect a diversion with the required confidence and raise a claim that the requisite material for a nuclear weapon is missing must meet a whole new standard. Such an error raises questions about how the IAEA views its role if it accepts the shortcomings of its own definitions.

The U.S. Department of Energy (DOE) has confirmed that 4-kg is sufficient for building a nuclear device in the case of Pu-239 and uranium-233 (U-233),[4]

and others have suggested that only 1-kg can be used for these isotopes.[5] This shows that 8-kg should be considered too large. The relevant assumption here is that materials for neutron reflecting and compression techniques are accessible by non-nuclear weapons states for making sizeable bombs with less material.

Leaving aside the omission about significant quantities, Kuperman, Sokolow, and Lyman do lay out the technical challenges in safeguarding these facilities, challenges that guarantee many kinds of diversions by determined proliferators would go undetected. Nowhere, however, might the technical capabilities of the IAEA prove less relevant than in the case of Iran and the current state of its nuclear program. The danger Iran presents is the advancement of its program under IAEA safeguards, thereby shortening the time needed for acquiring the requisite material for a nuclear weapon. With recent hopes for diplomatic progress in curtailing the program notwithstanding, Iran's program reveals a limitation to safeguards no matter the current capabilities or prospective improvements in them. Although analysts differ slightly in how much time Iran might need to acquire the material for one bomb (usually assumed to be 20- to 25-kg of U-235), continued enrichment of uranium to 3.5 percent and acquisition of additional centrifuge capacity could very shortly, if it has not already, make the time needed for assembly of a nuclear weapon so short that detection of a material diversion for bomb assembly could not prevent one from being built. This judgment holds important implications for the future of nuclear proliferation, as states learn they are able to come so close under IAEA safeguards to a nuclear weapon that the world has no choice but to act as if they have one.

This raises the question of whether it will become increasingly futile to focus on improving the ability to detect a material diversion from a fuel-cycle facility. The lower political and economic costs of pursuing nuclear weapons under the guise of a safeguarded civilian nuclear power program, where a state can be assisted in the effort from international suppliers or may be increasingly able to build the needed fuel-cycle technologies indigenously, suggest that the United States needs to define what it considers unacceptable along the spectrum of nuclear capability with regard to the fuel cycle. To draw the line at proscribing an Iranian nuclear weapon—as the United States may argue—would prove unmanageable. Once the requisite amount of material is produced, constructing and equipping a warhead is a relatively short and technologically straightforward process, almost certainly impossible to detect in a timely fashion. Not until a more effectual standard—and the credibility to enforce it—has emerged should improvement in the IAEA's abilities be regarded as helpful in preventing the manufacture of a bomb.

Kuperman, Sokolow, and Lyman have certainly provided a message that the nonproliferation community needs to hear more often, that the current technical capabilities of the IAEA make safeguarding fuel-cycle facilities very challenging. The bad news is that human factors and their interaction with these capabilities, as well as the inability of the United States to define what is unacceptable nuclear capability, make success in safeguarding less likely than even they suggest.

## ENDNOTES - CHAPTER 7

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# PART IV

# CHAPTER 8

# DISMANTLING THE SOUTH AFRICAN NUCLEAR WEAPONS PROGRAM: LESSONS LEARNED AND QUESTIONS UNRESOLVED

**Jodi Lieberman**

## INTRODUCTION

Reducing and ultimately eliminating nuclear weapons has been made a centerpiece of the Barack Obama administration. However, doing so requires sustained diplomatic engagement with other nuclear weapons states and, more importantly, effective verification and confidence-building measures to ensure the drawdown is transparent, verifiable, and irreversible. But, it would also be important to ensure that non-nuclear weapons states do not harbor a "bomb in the basement." Specifically, how might one verify that states that have previously developed a nuclear weapons program or produced weapons-usable material have properly declared them and given them up? History has shown that, while critical to nonproliferation efforts, the International Atomic Energy Agency (IAEA) is no match for a country intent on building a nuclear deterrent, even in the face of international enmity. It would therefore be instructive to look to previous examples in which a country accumulated significant nuclear "know-how," a deterrent, or weapons-usable material to identify any precedents and what they might suggest.

In the annals of history, there is only one country that has developed a nuclear weapons program,

a limited nuclear deterrent, and then dismantled that program and declared it for international inspection: South Africa. Between the 1960s and 1989, South Africa developed a limited nuclear deterrent and then opted to dismantle that deterrent, decommission its nuclear weapons complex, down-blend its nuclear weapons fissile material, come clean to the international community, and accede to the Nuclear Non-Proliferation Treaty (NPT) as a non-nuclear weapons state. For many, this was seen by the international community as an extraordinary turn of events, and South Africa has been lauded for these efforts. However, a deeper examination of the South African case raises a number of outstanding questions that beg the question of just how irreversible and transparent the South African disarmament was and how this might complicate current "getting to zero" efforts.

For example, before then-South African President F. W. de Klerk disclosed the nature of his country's nuclear deterrent, the program had been fully dismantled and upwards of 12,000 documents associated with the program destroyed. While some have noted that this was done to ensure that the incoming African National Congress (ANC) government was unable to access nuclear weapons know-how, the document destruction leaves a significant gap in what the world knows about the South African nuclear program 20 years hence. In addition, when IAEA inspectors examined the remains of the South African weapons program and attempted to verify how much weapons-usable highly enriched uranium (HEU) was produced, they were stymied by the significant material imbalances.

While inspectors claim they were able to reconcile those imbalances to within an acceptable level of

confidence, the question remains as to how acceptable that level of confidence is and whether there are unexplained imbalances that remain. These unresolved questions and our limited ability to answer them 20 years later suggests that actions should be taken to clarify the record regarding the South African program and to provide critical lessons as the United States pursues global nuclear weapons disarmament.

## DETERMINING HISTORICAL PRODUCTION: WHY?

While the move was considered a beacon of transparency, it is curious that de Klerk ordered the wholesale destruction of all documentation relevant to the nuclear weapons program **before** the IAEA had a chance to verify anything. He clearly knew that, to have credibility, the IAEA would have to be called in to verify the dismantlement and that this would require documentation. If the country really wanted to be transparent, then all relevant records for the enrichment facility would have had to be retained so that the IAEA could determine exactly how much HEU was produced. In fact, there was an IAEA safeguards team in South Africa when de Klerk made his big announcement.

According to the inspection team that led the verification process, there were a lot of unknowns, including being faced with a fuel cycle of indigenous origin, more than 20 years of enrichment activity, and unaccounted-for tails material that the South African government did not bother to measure. Even Waldo Stumpf, who actually ran the Atomic Energy Corporation of South Africa (AEC), has stated that:

> . . . the verification of the HEU output of the pilot enrichment plant against the natural uranium inputs, depleted uranium outputs and in-process losses posed a particularly difficult problem as far more U-235 is present in the more than 270 depleted UF6 cylinders than HEU.[1]

Why would Stumpf, who presumably was privy to all the relevant details of the fuel cycle as head of the AEC, declare that the verification process was challenging? Did the South Africans keep poor records? Did Stumpf believe that full dismantlement of the nuclear weapons facilities before the IAEA could get to them was a bad idea but was unable to say so publically?

It is also notable that, prior to the 1993 disclosure, the South African government used extensive cover stories and a deception plan to ensure that the IAEA, other governments, and the public were unable to discover the real nature of its "civilian" nuclear program. Those cover stories were used even while the IAEA was on the ground at the time of the de Klerk disclosure; AEC employees were instructed to lie to inspectors about various undeclared facilities that the team observed while there. So, it is questionable the extent to which the government was able to gain any credibility with the IAEA inspectors, having previously lied to them, in the aftermath of the big reveal. Further, any calculations about production and existing stocks of HEU in the public domain were done by extrapolation and assumption. Even the U.S. intelligence agencies were unable to verify the amount of material the South African government had in its complex.

To complicate matters, the IAEA will not disclose information about inspections in any member state; the information is deemed "safeguards confidential."

This is done to protect the nuclear expertise and the security of the country as well as the credibility of the IAEA to be an objective arbiter. Given the public nature of the South African disclosure, it is unclear if member states received a classified briefing to provide the details of the South African nuclear weapons program. It may have been left to the host country to make inspection information public, if at all. But, in the more than 20 years since its nuclear program was dismantled, the South African government has yet to disclose how much weapons-grade material it produced or where it came from, whether any of that technology or expertise was gained as the result of outside assistance, and exactly what became of the HEU.

After the 1993 disclosure, speculation was rife as to how much HEU its enrichment facility has produced. At the time, the South African government did not publically reveal how much HEU it had produced or that it had on hand, saying that not doing so was in the interest of nonproliferation and because the material was being stored at a single location. However, because it has disclosed that it had six gun-type nuclear devices, as well as other relevant information, analysts had to speculate as to how much HEU was involved. One estimate, calculated based on the amount of enrichment plant feed material, enriched product, depleted uranium tails, and separative work, concluded that South Africa had 731 (plus or minus 24 kilograms) of 90 percent enriched uranium, or enough material to build 12 Hiroshima-type fission bombs.[2] At the time, the IAEA was stymied with coming up with accurate material balances because, while the South African Atomic Energy Corporation "made precise measurements of the amount of HEU and LEU, and the U-235 assays of each,"[3] they paid little attention

to the depleted uranium (DU) tails. The tails, which were stored as UF6 in more than 600 cylinders, were not weighed or assayed accurately because, according to the South African government, they were of no economic value. The unaccounted for tails created a significant amount of uncertainty in the calculated HEU inventory. It is unclear why the AEC did not adequately keep track of the DU tails material. Perhaps they knew that this would be an important part of reconciling the actual throughput and production of HEU, should the program ever come to light. Was the sloppy record keeping, coupled with the extensive document destruction, part of an elaborate ruse to insert enough uncertainty in the accounting process to make it just credible enough to satisfy the IAEA inspectors and the member states?

After nearly 20 inspection missions, the IAEA alleged that it was able to ascertain that the declared inventory was consistent with the declared production and usage data but that the calculated isotopic balance indicated "apparent discrepancies" that could be "interpreted to indicate that an amount of U-235 was unaccounted for was actually the lack of an accurate accounting of the tails. Once the DU tails were measured, a process that took several years, inspectors claimed that the discrepancy was significantly reduced and that the HEU was fully accounted for. But, how does one know for sure? The production numbers were never made public. The facility itself had already been decommissioned, and the former employees clearly had an incentive not to tell the whole story: their financial compensation after they were put out of a job.

Because of the extensive history of the South African program, the IAEA was forced to review production records going back more than 20 years. But, what is not clear is whether adequate production records had been maintained such that verification of the HEU output of the pilot enrichment plant against natural uranium inputs, depleted uranium outputs, and in-process gas losses were accurately determined.

## THE BASE CASE: WHAT IS KNOWN ABOUT SOUTH AFRICA'S PROGRAM BEFORE DISARMAMENT

A number of political factors contributed to the decision taken by the South African apartheid government to develop nuclear weapons. From a technical perspective, it did so because it could. South Africa had a large indigenous supply of natural uranium, which was readily obtainable as a by-product of gold mining and refining. It was also a major supplier of uranium to the United States and United Kingdom during the first half of the Cold War. South Africa also had substantial economic resources and had benefited from the U.S. Atoms for Peace program. This included U.S.-origin 20 megawatt thermal (MWth) South Africa Fundamental Atomic Reactor Installation-1 (SAFARI-1)[4] research and radioisotope production reactor and the requisite 93 percent HEU fuel, provided until 1976. Before the United States imposed sanctions and severed ties with South Africa, it also trained South African nuclear scientists.[5]

Around the time the United States, under its Ploughshare Program for peaceful nuclear explosions (PNE), and the Soviet Union decided to explore using nuclear explosions for large scale engineering proj-

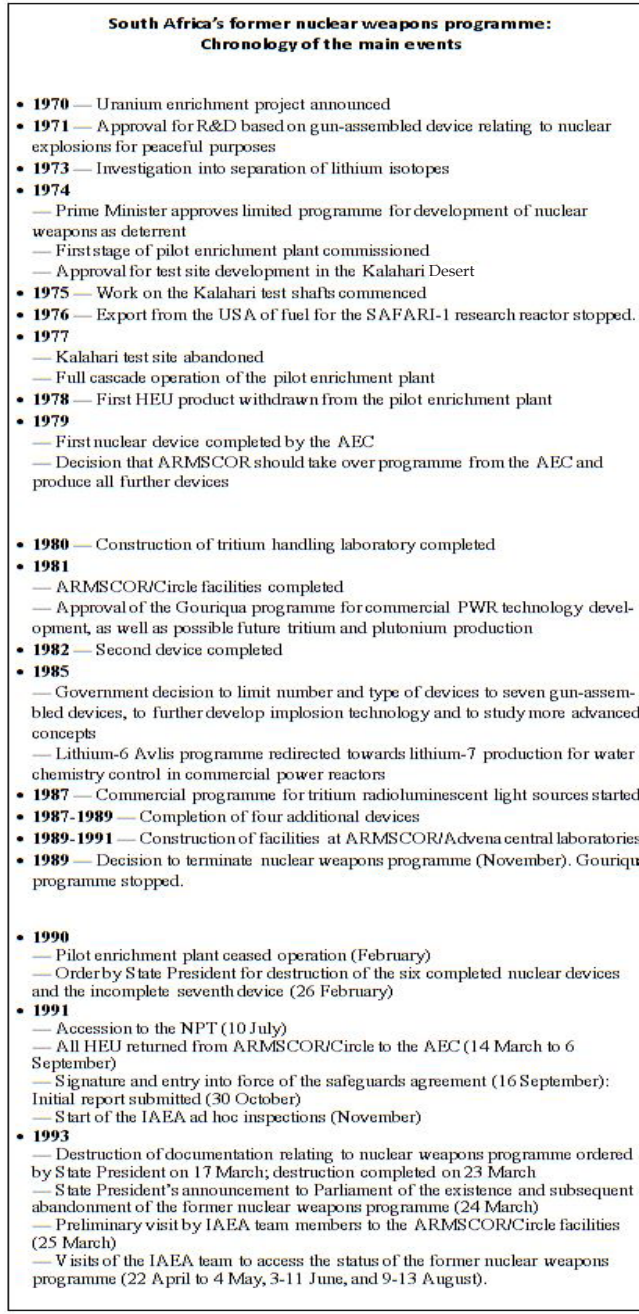
ects, South Africa followed suit. Initially, the intention was to develop its own PNE research program for mining, but it was ultimately transformed into a military nuclear weapons program sometime between 1973 and 1977.[6]

However, the outside assistance it had previously received to develop its civilian nuclear program enabled South Africa to develop an indigenous uranium enrichment process, and, subsequently, to master all aspects of a complete indigenous nuclear fuel cycle. It also constructed its own reactor as part of a plan to produce plutonium, the SAFARI-2, or Pelinduna reactor at Pelindaba. The reactor used 606 kilograms (kg) of 2 percent enriched uranium and 5.4 metric tons of heavy water, both supplied by the United States. The project was abandoned in 1969 so that South Africa could devote its resources to an indigenous uranium enrichment program.[7]

What is known is that South Africa had five key facilities associated with its program: Pelindaba,[8] the AEC site that housed the SAFARI-1 research reactor (RR), a hot cell complex, a waste disposal site, and conversion and fabrication facilities (nuclear weapons were built in an isolated section of the site, the Building 5000 complex); Pelindaba East (or Valindaba[9]), which contained the AEC Y-Plant for HEU production and the Z-Plant for LEU production; Vastrap,[10] which contained two nuclear explosive test shafts built in the 1970s in the Kalahari Desert; the Circle Facilities or Advena Central Laboratories, which were ARMSCOR facilities used in the 1980s/early-1990s for design, manufacture, and storage of nuclear weapons; and Somchem, the military facility involved in the development and manufacture of explosives and propellants. There was also the site at Gouriqua, in the Cape

Province, where South Africa planned to build a reactor facility for the possible production of plutonium and tritium.

South Africa completed its first gun-type nuclear weapon in November 1979, and its subsequent weapons were built at an average rate of one every 18 months.[11] Its pilot enrichment plant at Valindaba, the Y-Plant, allegedly produced about 100 kilograms of HEU per year over the course of its run from 1978 through 1989. The enrichment process South Africa had developed used "an aerodynamic technique similar to a stationary wall centrifuge in which uranium hexafluoride and hydrogen gas spin inside a small stationary tube."[12] By 1989, South Africa had six gun-type nuclear devices, each containing 55-kg of HEU, which were stored in Kentron Circle, the Advena facility. It also had a fully functioning HEU production facility and a semi-commercial LEU production facility at Valindaba. (See Figure 8-1.)



**South Africa's former nuclear weapons programme: Chronology of the main events**

- **1970** — Uranium enrichment project announced
- **1971** — Approval for R&D based on gun-assembled device relating to nuclear explosions for peaceful purposes
- **1973** — Investigation into separation of lithium isotopes
- **1974**
  — Prime Minister approves limited programme for development of nuclear weapons as deterrent
  — First stage of pilot enrichment plant commissioned
  — Approval for test site development in the Kalahari Desert
- **1975** — Work on the Kalahari test shafts commenced
- **1976** — Export from the USA of fuel for the SAFARI-1 research reactor stopped.
- **1977**
  — Kalahari test site abandoned
  — Full cascade operation of the pilot enrichment plant
- **1978** — First HEU product withdrawn from the pilot enrichment plant
- **1979**
  — First nuclear device completed by the AEC
  — Decision that ARMSCOR should take over programme from the AEC and produce all further devices

- **1980** — Construction of tritium handling laboratory completed
- **1981**
  — ARMSCOR/Circle facilities completed
  — Approval of the Gouriqua programme for commercial PWR technology development, as well as possible future tritium and plutonium production
- **1982** — Second device completed
- **1985**
  — Government decision to limit number and type of devices to seven gun-assembled devices, to further develop implosion technology and to study more advanced concepts
  — Lithium-6 Avlis programme redirected towards lithium-7 production for water chemistry control in commercial power reactors
- **1987** — Commercial programme for tritium radioluminescent light sources started
- **1987-1989** — Completion of four additional devices
- **1989-1991** — Construction of facilities at ARMSCOR/Advena central laboratories
- **1989** — Decision to terminate nuclear weapons programme (November). Gouriqua programme stopped.

- **1990**
  — Pilot enrichment plant ceased operation (February)
  — Order by State President for destruction of the six completed nuclear devices and the incomplete seventh device (26 February)
- **1991**
  — Accession to the NPT (10 July)
  — All HEU returned from ARMSCOR/Circle to the AEC (14 March to 6 September)
  — Signature and entry into force of the safeguards agreement (16 September): Initial report submitted (30 October)
  — Start of the IAEA ad hoc inspections (November)
- **1993**
  — Destruction of documentation relating to nuclear weapons programme ordered by State President on 17 March; destruction completed on 23 March
  — State President's announcement to Parliament of the existence and subsequent abandonment of the former nuclear weapons programme (24 March)
  — Preliminary visit by IAEA team members to the ARMSCOR/Circle facilities (25 March)
  — Visits of the IAEA team to access the status of the former nuclear weapons programme (22 April to 4 May, 3-11 June, and 9-13 August).

Source: Adolf von Baekmann, Garry Dillon, and Demetrius Perricos, "Nuclear Verification in South Africa," *IAEA Bulletin*, January 1995.

**Figure 8-1. IAEA Timeline of South African Nuclear Weapons Program.**

Whether or not South Africa received any outside assistance in the development of its nuclear weapons program beyond the building blocks provided through the Atoms for Peace program is subject to some question. President de Klerk claimed that the weapons were built without foreign assistance and that it never tested those weapons. Some have contended that South Africa received assistance from Israel, providing both tritium and other expertise, and there is evidence which lends credence to that contention. For example, a leaked 1988 court judgment revealed clandestine imports from Israel of tritium useful for boosting nuclear weapon yields.[13] The case involved a retired South African Air Force pilot who had transported some of the materials in question and later attempted to blackmail the government.

Interestingly, author Sasha Polakow-Suransky, a native Afrikaner, wrote in 2010 that he was provided documents by the ANC government proving that, in 1975, Israeli officials met with apartheid government officials to discuss selling nuclear weapons technologies to them, despite international sanctions prohibiting them from doing so. Meeting minutes declassified that year revealed that Israel helped South Africa "build highly advanced nuclear weapons delivery systems, long-range missiles up until 1989, when President de Klerk decided to scrap the nuclear weapons program."[14] It provided the technology upon the request of then defense minister P. W. Botha, who had asked for "nuclear-capable Jericho missiles." To this day, both South Africa and Israel refuse to acknowledge that the two countries had any relationship in which nuclear materials changed hands.

## HOW THE SOUTH AFRICAN NUCLEAR DETERRENT REMAINED A SECRET —OR DID IT?

Although there were many suspicions about the existence of a South African nuclear program, the government in Pretoria carefully cultivated a policy of ambiguity and secrecy that denied the world the smoking gun it needed to make a definitive judgment about the existence of its nuclear program or its nuclear ambitions. The government in Pretoria created sufficient ambiguity and took great pains to keep all aspects of its nuclear weapons enterprise secret: "… it is alarming how well Pretoria was able to cloak its bomb-making project for more than 15 years while more than 1,000 people worked on it."[15] South Africa's methods for concealment are instructive in trying to determine the activities in other threshold states.

In July 1970, then South African Prime Minister B. J. Vorster announced in a parliamentary speech that the government intended to develop an enrichment capability. Vorster stated that the pilot enrichment plant was to be built but that the government was not prepared to sign the NPT because it wanted to ensure secrecy and the proprietary nature of the technology and that South Africa expected to be producing 20,000 MWs of electricity domestically with nuclear power by the end of the century. Vorster added that South Africa would be enriching uranium domestically because of its abundant uranium resources and the desire to make the uranium economically attractive.[16]

The technology South Africa employed to enrich was indigenously developed by two scientists from the Council for Scientific and Industrial Research

(CSIR) in Pretoria, and based, in part, on the German Becker nozzle method.[17] The government then began development of its "Reactor Ontwikkeling" (RO) site for criticality experiments and PNE assembly at the Pelindaba site. As previously noted, the PNE program was originally created on the heels of a similar program being conducted in the United States and elsewhere for application in large-scale engineering projects. However, South Africa transitioned its PNE to develop a limited nuclear deterrent in around 1973-74. The RO building was "hidden by a ridge (an example of concealment via 'terrain masking') in the valley behind Pelindaba and was surrounded by up to three concentric security perimeters."[18]

At the time, former South African Foreign Minister Pik Botha was reported as having said that:

> It suited us that the West, and the whole outside world feared SA production of atomic weapons. We did not acknowledge their existence. In my discussions with the US over the years, my approach was what would we get in return for signing the NPT? Without ever admitting the existence of the bombs, I proceeded with the line "Let us assume the lady is pregnant. Now what can we do for such a lady?[19]

## DISARMAMENT AND DISCLOSURE— UNRESOLVED QUESTIONS

In the aftermath of the disclosure of the South African nuclear weapons program, disarmament experts and historians sought to reconstruct its precise nature, including how much material had been produced and how the program was built in extensive secrecy. However, research into the nuclear weapons history, even 20 years later, has been hampered by long-standing

secrecy laws, in addition to the destruction of records. Further, technical records that survived the apartheid-era destruction have remained secret, including those provided to the IAEA, as has the safeguards inspection report.

> A battery of secrecy laws was utilized during the program's lifetime to conceal the existence of South Africa's nuclear arsenal. But, although the need for concealment evaporated with de Klerk's decision to dismantle the programme, secrecy laws obstructing fuller public disclosure have largely persisted into the democratic era. . . . officials of two successive African National Congress-led governments have expressed strong objections to further disclosure beyond those made in 1993-1994.[20]

Although the South African constitution enshrines access to information, and the existence of the Promotion of Access to Information Act (PAIA) of 2000 and the establishment in 2002 of an interdepartmental Classification and Declassification Review Committee aimed at addressing apartheid victims' demands for access to records, are all intended to create a basis for greater openness, "many documentary requests have been rejected or delayed arbitrarily."[21]

Historians and nuclear experts have said they were frustrated by ANC members who once doubted apartheid-era officials' accounts of the past and subsequently showed "little inclination as government officials to unearth details and encourage a reexamination."[22] Moreover, as of 2003, some scientists who participated in the nuclear program still worked for the government, including Karel Fouche, general manager of the Pelindaba Nuclear Institute, who directed "a plant that used to make the HEU necessary

for weapons" and was "converted to commercial uses." Fouche said he mostly was privy to the science, not the strategy, of the weapons program. Information was highly compartmentalized, he said, adding that he doesn't believe there is much to tell."[23] But, it is the science and access to the nuclear know-how that is most critical in determining whether a latent nuclear weapons program could be rebuilt. It is also worth adding that South Africa continues to have a civilian nuclear power program as well as an extensive uranium mining infrastructure.

While some have stated that there is simply no need, given current geopolitics, to reconstruct a nuclear weapons program, history has shown that a change in circumstance, along with political will, access to information, and the ability to pursue a program under the cloak of secrecy, is all that would be required to do so.

In addition, the disclosure of nonsensitive information by current and former nuclear weapons program employees is also prohibited by secrecy laws. Nuclear Energy Act 46 of 1999 prohibits the disclosure of any information about AEC activities with respect to "restricted matter." Nuclear program personnel were also required to sign an oath pledging to comply with nondisclosure laws during and after their employment. Former AEC head Waldo Stumpf negotiated a nondisclosure agreement with the ANC government that binds him to perpetual secrecy as part of a financial settlement upon his departure.

**The U.S. Government Questions South Africa's Disclosure.**

In addition to the IAEA inspectors' suspicions prior to the 1993 disclosure, debate over the completeness of the South African government's inventory disclosures to the IAEA were actively debated within the U.S. Government. A December 19, 1993, document produced by the intelligence community stated that "South Africa went to considerable lengths not to acknowledge to either the IAEA or the public the military orientation and advanced stage of the former program. . ."[24] The intelligence bureau analysts at the U.S. Department of State took issue with the assertions by the Central Intelligence Agency (CIA) that questioned the completeness of the South African material declaration regarding the amount of HEU it had produced. State asserted that, despite the CIA's conclusions, the South Africans "reportedly kept poor operating records of enriched uranium output" so making a firm conclusion of cheating was not possible at that time.[25] In a second memo to the Nonproliferation Center, State noted that it strongly believed that:

> the collective body of information is ambiguous, and contradictions must be resolved before any firm judgments can be offered with confidence. Some information tends to support the notion of an "honest declaration"; some tends to support the "cheating" scenario; and much is open to both interpretations. There is no basis at present for assigning greater likelihood to the "cheating" scenario. More importantly, we feel it is premature to offer any general verdict at present on South Africa's conduct.[26]

## IAEA INSPECTIONS—MORE QUESTIONS THAN ANSWERS

When President de Klerk announced that South Africa had indeed developed a limited nuclear deterrent, the IAEA had a team of inspectors on the ground. According to a report by Adolf von Baeckmann, Garry Dillon, and Demetri Perricos, this led the IAEA to "augment its safeguards team in South Africa with, among other specialists, nuclear weapons experts." The team "thoroughly examined detailed records of nuclear materials in South Africa" and was able to conclude that "there were no indications to suggest that the initial inventory was incomplete or that the South African nuclear weapons programme had not been completely terminated and dismantled."[27]

However, it was later revealed that the inspection team had difficulty in coming to these conclusions, partly because the South African program had a number of indigenous facilities that had not previously been subject to safeguards. Moreover, South Africa refused to make public the amount of HEU it had produced due to alleged concerns about proliferation. Finally, the team found that the calculated isotopic balance indicated discrepancies with respect to the HEU produced by the Y-Plant and the LEU produced by the Z-Plant. The team concluded that there could be some U-235 that was unaccounted for. Further complicating matters was the absence of accurate accountancy of the depleted uranium waste stream. They had to resort to records regarding the recovery of HEU following shutdown of the enrichment facility. Since the facilities had been dismantled before the IAEA team was able to conduct inspections, they were completely reliant upon whatever records were made available to

them as well as re-creation of plant operation. This meant they had to be authentic in order to be credible. Was the team able to authenticate those records? As many of those involved in the weapons program had also signed nondisclosure agreements in order to get their full government retirement compensation, how much did they tell the IAEA inspectors? Were they fearful that they would lose their compensation if they said too much? Even the former head of the AEC admitted that:

> Verification by the IAEA of the completeness of South Africa's declaration of inventory of nuclear material and facilities was 'no easy task' and that the inspection team would be 'forced to delve into the past…'.[28]

## MATERIAL BALANCES AND MUF

When the IAEA began its inventory inspections at the declared South African facilities in 1991 following its accession to the NPT, the inspection team found a number of decommissioned and partially or wholly dismantled facilities, including those that had produced HEU and LEU, because President de Klerk had ordered their dismantlement 2 years earlier. Much of the verification therefore rested on the documentation, records, and interviews that the South African government was able to furnish. At the time, the team concluded that the information provided by the government—the operating records of the decommissioned pilot enrichment plant—were insufficient to make any firm conclusions about the validity of the declaration. It requested additional information, including the historical values of material unaccounted for (MUF), as determined by the AEC for "financial control," the

historical flows of nuclear material, including imported material, and accountancy and operating records of the semi-commercial enrichment plant. The South African government did provide those documents, which indicated that production of enriched uranium was suspended between August 1979 and July 1981 due to technical problems. The AEC claimed that production fluctuated depending on the operational situation at the plant, withdrawal of LEU for production of Koeberg fuel elements, introduction of DU feed material, etc.[29]

However, when the team calculated the U-235 balance in the pilot enrichment plant, it found a discrepancy it attributed to the fact that the AEC lacked a "formal measurement control program" for the depleted uranium product, which accounted for a significant amount of the U-235 balance. The AEC claimed at the time that they did not measure the DU formally because the plant management placed a "low financial value" on it. The team found a similar problem when trying to reconcile the material balances at the semi-commercial enrichment plant; that is, the team once again came up with a discrepancy in the U-235 balance. Again, the team ascribed it to the material accounting system. Upon further investigation, the IAEA inspection team determined that the:

> accuracy of the physical inventory was impaired by the non-availability of suitable instruments to measure process hold-ups, the unwillingness of the plant management to interrupt production in order to drain condensers or to transfer material to measurement points, and to the lack of comprehensive measurement control programmes. The calculated values of [MUF] for each year of operation were provided to the team by the AEC, but were not taken into account in the

> evaluation of the U-235 balances in view of the uncertainties associated with their determination.[30]

As a result, the team did not do a complete mass balance of the material at the enrichment sites.

Following the disclosure of the nuclear weapons program in 1993, the IAEA set about trying to reconcile the apparent discrepancies it discovered during pre-disclosure inspections. It received access to additional records and technical reports from the AEC, including the description of "phenomena, such as chemical losses, which were unique to the process gas mixture and the plan construction materials which influenced the output of the plant."[31] Given further "clarifications" provided by AEC officials and examination of additional historical records, the IAEA team concluded that the "magnitude of the apparent discrepancy in the U-235 balance associated with the pilot enrichment plant was reduced to such a level" that it could conclude that there was simply reasonable in-process losses.[32]

> Having regard to the uncertainties normally associated with data of this nature, it is reasonable to conclude that the uranium-235 balance of the high enriched uranium, low enriched uranium and depleted uranium produced by the pilot enrichment plant is consistent with the uranium feed.[33]

What is puzzling about this statement is that the team made this assertion despite the fact that it was unable to conduct a complete mass balance calculation because the AEC did not assay or weigh the tails and other material it deemed "waste," including some material that contained significant amounts of HEU. The team was also unable to obtain records with re-

spect to the amounts of natural and depleted uranium used in experimental or the material transferred to the nuclear weapons program "on the grounds that natural and depleted uranium had been considered ordinary metal with little nuclear significant or financial value."[34]

When IAEA Safeguards Department management raised questions about the lack of a mass balance, the South Africans were forced to assay and weigh the amount of material in the roughly 600 cylinders deemed waste. In so doing, they discovered a lot more HEU than had originally been determined by the inspection team. But, did it account for all of the HEU in the tails material? And what about the holdup material the team was unable to access?

An October 1993 report[35] estimated that the South African government had roughly 731-kg (plus or minus 24-kg) of 90 percent uranium on hand at the time of the disclosure. This was an inventory difference equivalent to the material required to make two bombs. The South African estimate of the amount of depleted uranium tails from enrichment plant operations was 370,643-kg. Taking into account the amount of material needed to start up the pilot enrichment plant and bring it to equilibrium, and the amount of fuel it produced for the SAFARI-1 research reactor and the Koeberg reactors, including how much each required given their respective designs, the report estimated that, had the pilot enrichment plant produced only HEU for weapons, it could have produced roughly 1000-kg of 90 percent uranium.

> The South African AEC estimated [sic] of the relative uncertainty (one standard deviation) in the tails assay is 15.6 percent. This, already large error in the tails

assay, produced a corresponding relative uncertainty in the calculated inventory of HEU product that is about twice as large—about 35 percent.[36]

Moreover, the gun assembly device dropped on Hiroshima—Little Boy—was built using about 50-kg of HEU enriched to 80 percent and had a yield estimated between 12 and 15 kiloton (kt). The yield range of the South African weapons was estimated to be about 10- to 18-kt. It was unknown, however, how effective the neutron reflector was in those weapons compared with the one in Little Boy. Therefore, the South African weapons could have needed as much as 60-kg of 90 percent enriched uranium per warhead. Based on what was known about production at the pilot enrichment plant, it was capable of producing enough HEU for an additional five weapons of the same design. The inventory difference, or MUF, represents another two nuclear weapons' worth, which could have been in the tails material or elsewhere.

## LESSONS LEARNED, OPEN QUESTIONS, AND WHY THEY MATTER NOW

It has been 20 years since South Africa disclosed that it had built a limited nuclear deterrent and then dismantled it. But, despite the many writings on the subject, significant gaps in public knowledge remain. How thorough was the IAEA in reconciling HEU production? Why did the de Klerk government destroy many of the "smoking guns" from the program **before** the IAEA could get to them? How successful was the IAEA team in reconciling historical fissile materials production even though the physical plant no longer existed? Much of the secrecy the South African gov-

ernment instituted in the wake of the dismantlement is still in place, despite the fact that the program has allegedly not existed for 20 years.

The South African disclosure has been held up as a beacon of transparency and of rollback of a nuclear weapons program. But, in the context of the current administration's commitment to eliminating nuclear weapons, the South African case raises at least as many questions as the IAEA has purported to have answered about the program. Questions about the amount of fissile material the South African complex actually produced, the remaining secrecy surrounding the program, the destruction of documentation and facilities prior to the disclosure and IAEA inspections of the weapons facilities, and the completeness of the IAEA's verification of the South African program all beg the question of how a country would give up a nuclear weapons program now, how it could be effectively verified, and how much confidence the public—and other governments—would have in that verification. The confidence level would have to be particularly high in order for any other country to follow suit and similarly disarm. It would also have to be high in order to convince non-nuclear weapons states that the threat has been eliminated. If the standard accorded to South Africa by the IAEA and its Member States back in 1993 were used in the context of the current "getting to zero" campaign, it is unclear that the book would be deemed to have been verifiably closed.

## ENDNOTES—CHAPTER 8

1. Waldo Stumpf, "The Birth and Death of the South African Nuclear Programme," presentation given at the Conference "50 Years After Hiroshima," held at Castiglioncello, Italy, September 28-October 2, 1995.

2. Thomas B. Cochran, "High-Enriched Uranium Production for South African Nuclear Weapons," *Science and Global Security*, Vol. 4, No. 2, Winter 1993/94.

3. *Ibid*.

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16. Pabian.

17. One of the CSIR scientists, W. L. Grant, received reactor physics training in the United States.

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19. Former South African Foreign Minister RF 'Pik" Botha in an interview with Dr. Sue Onslow (LSE IDEAS Fellow) Pretoria, July 15, 2008, p. 12, available from *www.lse.ac.uk/IDEAS/programmes/africaProgramme/pdfs/bothaInterview.pdf.*

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28. Stumpf.

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# CHAPTER 9

# VERIFYING THE DISMANTLEMENT OF SOUTH AFRICA'S NUCLEAR WEAPONS PROGRAM

**Olli Heinonen**

## INTRODUCTION

In its 2011 annual Safeguards Statement, the International Atomic Energy Agency (IAEA) determined that for 58 states where both the Comprehensive Safeguards Agreement (CSA) and Additional Protocol (AP) are in force, it:

> found no indication of the diversion of declared nuclear material from peaceful nuclear activities and no indication of undeclared nuclear material or activities. On this basis, the Secretariat concluded that, for these States, all nuclear material remained in peaceful activities.[1]

This rolling safeguards report that provided a yearly review of the status of IAEA member states' nuclear activities was noteworthy as South Africa was, for the first time, included in the group of states.[2]

In September 1991, South Africa concluded a CSA with the IAEA and submitted its initial declaration on facilities and nuclear material inventories (a summary of South Africa's nuclear program prior to its conclusion of a safeguards agreement is included in Appendix 9-I). The same year, the IAEA General Conference requested that the IAEA Director General "verify the completeness of the inventory of South Africa's nuclear installations and material and to report to the

Board of Governors and to the General Conference."[3] This request was made following the entry into force of South Africa's safeguards and previous long-standing claims made regarding the existence of a possible nuclear weapons program.

While the South African government in Pretoria had already taken the political decision and had dismantled its nuclear weapons program prior to signing a safeguards agreement with the IAEA, it was only in March 1993 that President F. W. de Klerk disclosed South Africa's nuclear weapons program. South Africa's initial nuclear material inventory submitted to the IAEA in 1991 had not contained any reference to its past nuclear weapons program. The IAEA Secretariat's first verification report submitted to the General Conference in September 1992[4] did not mention any indications of a weapons program either, though it concluded that there were "apparent discrepancies" in calculated U-235 isotope balances at the pilot enrichment plant and semi-commercial enrichment plant.

Following Pretoria's disclosure, the IAEA's verification work was extended from 1993 to confirm dismantlement and to put in place mechanisms that would allow for early detection should the weapons program be reconstituted. Parallel to this, inspectors initiated a more extensive examination of nuclear material flows and verification of the historical production of low and highly enriched uranium. By the time of the next verification report in September 1993, the Secretariat was able to conclude, by tallying up prior unreported amounts of highly enriched uranium (HEU) that were used for the weapons program, that the amount of HEU that could have been produced by the pilot enrichment plant was consistent with the amount declared in the initial report.[5] However, at

that stage, work for the verification of the completeness of low enriched uranium production continued.

## VERIFICATION CHALLENGES

While South Africa's initial declaration to the IAEA was meant to include all information on all nuclear material subject to safeguards, the weapons-related aspects of the South African program were omitted from its initial report. The IAEA was provided with historical accounting and operating records of enrichment plants and other facilities, but records provided to inspectors did not include any reference, *inter alia*, to conversion of highly enriched uranium hexafluoride to uranium metal and further to weapon components. Similarly, its initial report did not mention the existence of such facilities. It is worth mentioning that the IAEA's annual safeguards statements for 1992 only mentioned that the verification of South Africa's initial declaration was proceeding without any reference to possible concerns about the completeness of declarations.

Events took a clear turn with regard to the IAEA's verification activities following South Africa's disclosure. Objectives to inspections took on added dimensions. Assurances were sought that:

1. all nuclear material in South Africa had been placed under IAEA safeguards and is in peaceful use,
2. all nuclear weapons, their components, and related manufacturing equipment had been destroyed,
3. all nuclear weapons-related installations had been fully decommissioned or converted exclusively to peaceful nuclear use, and
4. mechanisms that allowed for early detection of restoration of any nuclear weapons capability were put in place.

The first benchmark for the IAEA in terms of nuclear material accountancy undertaken was to tally up enriched uranium stocks and ensure that no significant quantity of highly enriched uranium was missing from the declared inventories (the absence of nuclear material for one or more nuclear weapons could have been concealed, e.g., by overstating nuclear material inventories or MUFs).

In equation form:

$$MUF = BI + X - Y + HU + BE$$

Where,

BI= Beginning physical inventory
X= Inventory increases, then
Y= Inventory decreases
HU = Holdup
BE = Ending inventory unaccounted for

By the time the IAEA was called upon to verify South Africa's dismantled nuclear weapons program, the agency was already in the midst of strengthening its safeguards verification process. New winds started to blow in the early-1990s after the discovery and dismantlement of an undeclared nuclear program in Iraq, where it soon became obvious that an enhancement of the effectiveness of the IAEA safeguards system was needed. As a result, a number of safeguards measures were strengthened, including those that were being applied to safeguards undertaken in both North Korea and South Africa. The enhanced evaluation process brought together not only declared data and verification results through a statistical analysis based on the propagation of the operators and inspectors measurement errors in order to detect diversion

of declared material into material imbalance, but ways were also sought to more closely corroborate data and trends, such as cumulative MUFs, performance of the operators' nuclear material accountancy system, and operator/inspector measurement differences.

Another new development being implemented in the South African case was the re-examination of verification processes involving nuclear materials. Non-nuclear production parameters were also evaluated alongside the overall consistency of nuclear material accountancy records. To cite an example, uranium metal quantities must be consistent with parameters to produce uranium metal. In such a process, uranium tetra fluoride (UF4) is reduced to uranium metal using customarily calcium on magnesium metals. The process produces ashes and slag, which contain calcium or magnesium. The amounts of these elements found in wastes should be in conformity with the uranium metal produced. Furthermore, the amounts of ashes and slag need to match with the stated amounts of uranium metal produced. Similarly, one can estimate losses in casting and machining of uranium metal components to their final forms. Again, those need to match up with the amount of uranium metal produced. Evaluation of the choke points, for example for a production chain, yellowcake—UO2—UF4—UF6—enrichment—UF4—uranium metal, provides additional assurances about the completeness of a state's declarations.

While the enhancement of safeguards measures was still evolving and in its early days, South Africa's declaration that it had given up its nuclear weapons and would open its nuclear program to safeguards provided inspectors the learning process and experience that helped shaped a more analytical safeguards process.

The South African case had essentially two dimensions under which verfication activities fell: dismantlement and assurances. These processes, while not the same, were also not exclusive and overlapped. In fact, one could not be achieved fully without the other. Assurances that all (present and future) nuclear activities would remain in peaceful use meant reconstructing and understanding the historical aspects of the weapons program. In South Africa's case, even with the case of admission of a weapons program and subjecting its program to IAEA dismantlement, there were gaps of ambiguity that the agency faced. While it is unlikely to ever achieve a 100 percent score, the IAEA's role was to provide the necessary assurances required to both dismantle and prevent reconstitution of the weapons program.

Prior to disclosure, South Africa had destroyed documents related to the design and manufacturing of nuclear weapons. However, at the same time, thousands of operating records, including historical accounting and operating records of its two enrichment plants and uranium conversion and fabrication plants, were available to the IAEA. Such papers were, however, far from sufficient in themselves to detail a full picture. For instance, some of the wastes, scrap, and tails were poorly characterized in terms of their nuclear material quantities. The enrichment plant used to produce highly enriched uranium mainly for the weapons program had already been dismantled, while the other was still kept operational until 1995. From a technical perspective, the challenge was to estimate uranium holdup in equipment. Precise verification of nuclear material held in equipment was only possible from equipment decontamination liquors or sludges, which was time consuming and stretched

over many years. Until then, the starting point of the holdups had to be based on estimates.

As a result, the first material balances tallied by the IAEA after 1991 resulted in an apparent discrepancy in the U-235 balances of the two enrichment plants.[6] With respect to HEU produced by the pilot enrichment plant and LEU produced by the semi-commercial enrichment plant, it showed a substantial amount of unaccounted for uranium-235. After the first evaluations in 1992, the IAEA continued with the re-examination of records, additional decontamination activities, and further sampling to obtain more precise estimates of nuclear material in wastes, tails, and holdups.

Another difficulty in confirming the statements made by South Africa was the fact that some of the installations that were used for its nuclear weapons produced nuclear material for both its civilian and military parts of the nuclear program. As a result, for example, wastes were mixed, hence complicating verification assessment. This technical matter alone, which has an impact on the wider picture of determining South Africa's nuclear program, resulted in additional and further verification steps. The dismantling, decontamination, and re-characterization of the wastes extended well over a decade.

The nuclear waste storage facility held tens of thousands of drums containing substantial amounts of high and low enriched uranium waste from the former enrichment plants and other decommissioned facilities (see Figure 9-1).

**Figure 9-1. Temporary Storage of Waste Drums in a Decommissioned Enrichment Plant.**[7]

During the re-characterization process, the contents of each drum were recorded after opening it, and nuclear material quantity was verified using special drum scanners (see Figures 9-2 and 9-3).

**Figure 9-2. All Waste Drums Opened, Contents Characterized, and Nuclear Material Verified.**[8]

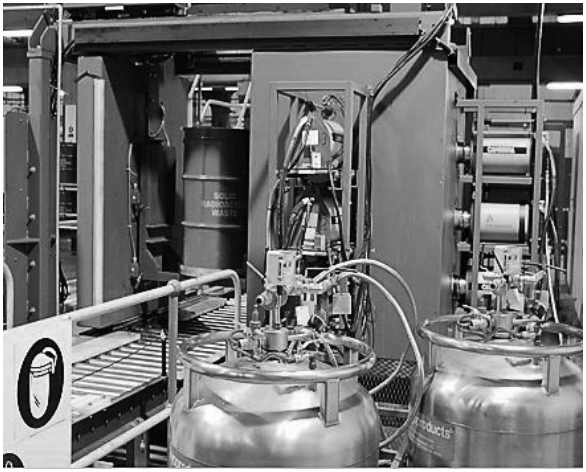

**Figure 9-3. IQ 3 Scanner Used for Verification of Uranium in Waste Drums.[9]**

## LONG-TERM MONITORING

After deciding to terminate its nuclear weapons program in 1989, South Africa proceeded with dismantling its weapons and related infrastructure, including the destruction of weapons-related documentation without the presence of the IAEA.

To confirm the statements made by the South African authorities and to set up a baseline to monitor that the program or its parts were not reconstituted, the IAEA had extensive discussions and briefings by former staff personnel to understand the country's nuclear program from a "cradle to grave" approach. Such information received was reconciled with other information received by IAEA from other member states; compared against dismantlement records kept by the South African authorities; and cross-checked against independent IAEA nuclear material verification results, facility designs, and environmental samples tak-

en. These steps were undertaken to create an independent understanding of the chronology and contours of South Africa's nuclear program. Apart from the IAEA using its tools available to draw its own conclusions, the verification process was also a dynamic process of dialogue with South African authorities that defined what assurances were further required along the way. For example, the IAEA made additional suggestions to Pretoria to destroy additional equipment and to render the test shafts in Kalahari useless.

Due to the embargos imposed under apartheid rule and the secrecy that necessitated the development of its nuclear weapons program, South Africa established an extensive indigenous industrial infrastructure to support its civilian and weapons programs. This infrastructure produced, *inter alia*, equipment and components needed for its enrichment program. This created a different problem: While the IAEA was monitoring nuclear installations and materials under the safeguards agreement and verifying dismantlement, some of the South African companies involved in nuclear weapons-related matters became engaged with the illicit nuclear trade. For instance, one of the companies had built Libya's uranium hexafluoride feeding system and was only busted in 2003 when the A. Q. Khan clandestine nuclear network was unraveled. While it is known that part of the process of dismantlement also included rehabilitation of personnel involved in nuclear weapons work, the clandestine and indigenous nature by which states like South Africa operated have meant that some of the companies managed to slip the attention of the IAEA and also, apparently, that of the South African authorities.

## CONCLUSION

There are a few lessons to be drawn from the IAEA's role in verifying South Africa's dismantled nuclear weapons program. Long-term monitoring and verification of nonproliferation efforts are necessary and require a significant period of time, even with self-disclosure of nuclear weapons, as seen in South Africa's case. The fact that secret nuclear programs, like South Africa's, often develop their own indigenous processes throws light on the need for monitoring all such nuclear-related facilities. Attention should also be given to understanding the extent of indigenous production capabilities and their potential links to nuclear proliferation.

Verification work is painstaking as well as time and resource consuming. Inspectors are faced with ambiguities, inconsistencies, and gaps. A historical and composite understanding of the nature and dimensions of a nuclear program, including the military/weapons dimensions, is needed to ultimately provide the assurances of a peaceful nuclear program. Because the IAEA needs to draw its own conclusions and corroborate information it is provided by the inspected state, details and (re)examining issues from various perspectives are required. This is not a case of nitpicking but a step within the larger verifications process in order to derive the correctness and completeness of a program that had developed in a clandestine nature.

The IAEA has the necessary tools and practices to verify nuclear inventories, map the chronologies of a nuclear program, and suggest additional steps needed to be taken by the inspected state to help the IAEA fulfill its requirements. Each case of nuclear concern and complexity is different, and prescriptions may differ

but have the same aim of ultimately providing the international community the needed assurance of a peaceful nuclear program. In the case of South Africa, much of the weapons-related information had been destroyed, and weapons and their manufacturing installations had been dismantled without the presence of the IAEA inspectors. While there can be a number of conjectures as to why South Africa chose to do so, it is clear that the process of verification after the fact of dismantlement having taken place meant time added to the clock for the IAEA in terms of providing assurances on the completeness and correctness of South Africa's nuclear program.

Since only limited verification was possible during the operation of the nuclear facilities, and parts of the program were dismantled without the presence of the IAEA, any final assessment would have to be reconciled with the fact that an absolute account of every single event is unlikely. However, through the refinement of the material balance evaluations process, coupled with verified information that became available from decontamination activities carried out and the recharacterization of wastes, the IAEA was able to state, after a period of time, that there is no reason to indicate that the nuclear material inventory of South Africa is incomplete.

Aside from the IAEA's verification requirements, full cooperation and transparency from the authorities and operators of the inspected state are equally essential in resolving outstanding issues. South Africa's policy—access any time, any place with a reason—was important for the IAEA work. Its authorities also cooperated with and provided access to people who were working in its weapons program during the various phases. Ongoing inspections and verification

work conducted, along with the accommodation and cordial cooperation provided by the South African government to the IAEA, were ingredients that eventually put the country back on the path to attaining its full bill-of-health assessment in 2010.

## ENDNOTES - CHAPTER 9

1. "Safeguards Statement for 2011" and "Background to the Safeguards Statement," IAEA, available from *www.iaea.org/safeguards/documents/es2011.pdf.*

2. South Africa concluded a Comprehensive Safeguards Agreement in 1991 and adopted the Additional Protocol in September 2002.

3. General Conference Resolution GC(XXXV)/RES/567, IAEA, September 1991, available from *www.iaea.org/About/Policy/GC/GC35/GC35Resolutions/English/gc35res-567_en.pdf.*

4. The Denuclearization of Africa, GC(XXXVI)/1015, IAEA, September 4, 1992, available from *www.iaea.org/About/Policy/GC/GC37/GC37Documents/English/gc37-1075_en.pdf.*

5. The Denuclearization of Africa, GC(XXXVII)/1075, IAEA, September 9, 1993, available from *www.iaea.org/About/Policy/GC/GC37/GC37Documents/English/gc37-1075_en.pdf.*

6. According to the provisions of the safeguards agreement, the IAEA Secretariat can disclose information about nuclear material inventories only with the consent of its Board of Governors or the concerned Member State. In the case of South Africa, the agency has not made public any nuclear material accountancy information, also due to security reasons.

7. T. C. Hlongwane, "NECSA [Nuclear Energy Corporation of South Africa] Solid Radioactive Waste Management Plan," Regional Practical Workshop on the Decommissioning of Radioactive Contaminated Facilities, August 24, 2011.

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## APPENDIX 9-I

In the 1970s and 1980s, South Africa's nuclear program focused first on the manufacture of a gun-type device, and subsequently pursued research and development (R&D) for an implosion-type nuclear device. In the 1970s, Pretoria's Atomic Energy Commission's nuclear weapons-related work was concentrated at Pelindaba (Building 5000), where criticality experiments were conducted to develop a gun-type nuclear device.[1] The area had also housed R&D laboratories, as well as premises for the machining of uranium metal components for a first nuclear device, which was completed by 1979.[2]

When the decision to develop deliverable nuclear weapons was made later in the 1970s,[3] the Kentron Circle Facility (Advena Circle Facility or Advena Central Laboratories) was built for the production of South Africa's second nuclear device, followed by the construction of four other gun-type weapons. Physically, the Kentron Circle Facility was located in an entirely separate geographical area a few kilometers away from Pelindaba. Services of Somchem, an ARMSCOR weapons-dedicated facility, were also used for the development of explosives for nuclear purposes. This phase of the nuclear weapons R&D program included studies on possible use of tritium boosted devices, research on implosion, and thermonuclear technology, and the production and recovery of plutonium and tritium.[4]

South Africa also built testing areas for its nuclear weapons program. The Vastrap test range was located in the Kalahari Desert and had two nuclear test shafts.[5] The test shafts had a depth of 385 and 216 meters, respectively.[6] The shafts were sealed off in 1993 under IAEA supervision.

Highly enriched uranium was a natural choice for Pretoria's weapons program given its rich uranium ore resources. In 2011, South Africa retained 5 percent of the world's known recoverable uranium resources.[7] By 1952, South Africa had started producing uranium. At the peak of its mining program, until 1965, South Africa operated 26 mines, but since then, mining has decreased. In 2012, South Africa produced 465 tons of uranium, which is less than 1 percent of world production.

Today, South Africa maintains one operating uranium recovery plant, the Vaal River South uranium plant,[8] compared to the early-1980s when it operated three uranium production plants.

## FACILITIES UNDER SAFEGUARDS BEFORE SEPTEMBER 1991

Before 1991, and the conclusion of a comprehensive safeguards agreement with the IAEA, there were three installations under IAEA Information Circular 66 safeguards agreement in South Africa.

### Research Reactor.

In 1965, South Africa Fundamental Atomic Reactor Installation (SAFARI-1), a 20-megawatt (MW) light water reactor, started operation in Pelindaba. The reactor had an original supply of 90 percent highly enriched uranium (HEU) fuel from the United States until 1976.

**Hot Cell Complex, Pelindaba.**

The Hot Cell Complex facility at Pelindaba has been used for isotope production purposes. South Africa is today one of the main molybdenum-99 producers. In 1984, South Africa made a policy decision—due to risks that the IAEA may find clandestine operations—that the installation would not be used for the R&D on plutonium reprocessing. For the same reason, the SAFARI-1 reactor was not used for any plutonium production experiments.

**Koeberg Nuclear Power Plant.**

The Koeberg Plant, commissioned in 1984-85, was designed and built by Framatome, France. It has twin 900-megawatt electrical class pressurized water reactors.

## ADDITIONAL NUCLEAR INSTALLATIONS DECLARED IN SEPTEMBER 1991

The initial declaration included a number of nuclear facilities, laboratories, and small locations using nuclear material. South Africa also had uranium enrichment studies using gas centrifuges and working with laser enrichment. The major installations related to uranium enrichment, uranium processing, and nuclear material storage and recovery are as follows.

**Uranium Conversion.**

In the 1960s, South Africa started small-scale uranium conversion experiments. A uranium conversion facility was built in the early-1980s to produce feed

material for uranium enrichment. At some point, South Africa also constructed, and operated, a second UF6 production plant. It was shut down by 1998.

**Pilot Uranium Enrichment Plant, Y-Plant.**

Production of HEU (this facility also produced low enriched uranium [LEU]) began in January 1978 and ended in November 1989 at Valindaba, adjacent to the Pelindaba site. The United States stopped exporting HEU fuel for the SAFARI-1 reactor in protest against the construction of Y-Plant and South Africa's nuclear weapons program. The Y-Plant then started producing 45 percent enriched uranium in 1979 for SAFARI-1. The plant was already under decommissioning when Pretoria provided its initial declaration to the IAEA.

**Semi-Commercial Enrichment Plant, Z-Plant.**

Production of low enriched material began in August 1988 at Valindaba. The plant was still in operation when Pretoria submitted its initial state declaration in 1991. Enrichment activities at the plant were terminated in October 1995. Prior to shutdown, the Z-plant had a capacity of 300,000 separative work unit (SWU)/yr. It supplied 3.25 percent enriched uranium for the Koeberg Plant. Originally, fuel for Koeberg was imported. During the height of sanctions, South Africa's AEC was tasked to set up and operate uranium conversion, enrichment, and fuel manufacturing services to keep the Koeberg reactors in operation. (See Figure 9-AI-1.)

**Figure 9-AI-1. View of the Enrichment Plant before Dismantlement**.[9]

**Highly Enriched Uranium Fuel Fabrication.**

The pilot scale plant was built to produce fuel elements for the SAFARI-1 research reactor after the United States stopped the fuel deliveries in 1976.

**LEU Fuel Fabrication Plant.**

The fuel fabrication plant produced LEU fuel elements for the Koeberg power reactors.

There was also a zircaloy tubing facility in Pelindaba to produce cladding for fuel assemblies used in Koeberg reactors. In 1993, it was closed and sold to a Chinese enterprise.

**Decontamination Plants and Waste Storages.**

These plants are at Pelindaba and are used for decontamination of equipment, storing of wastes, and packing wastes for the final disposal.

**Spent Fuel and Waste Disposal.**

South Africa has two radioactive waste disposal sites: the Thabana Hill site and the Vaalputs National Waste Repository.

## ENDNOTES - CHAPTER 9, APPENDIX I

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6. Albright.

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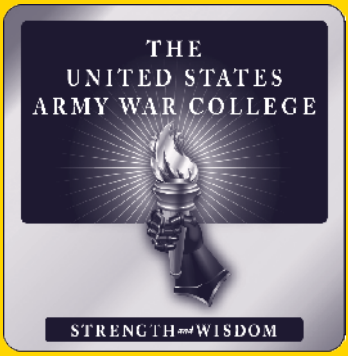


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